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On usability and vulnerability in radiotherapy

- sketching out a 'subtask perspective'

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Synopsis

This thesis examines the concepts of usability and vulnerability. Through the creation of a new perspective, the 'subtask perspective', the concept of usability is transferred from the field of human-computer interaction to a perspective more concerned with the safe and reliable performance of systems. This thesis aims to argue why this 'subtask perspective' can positively affect a systems ability to detect and handle vulnerability. The perspective is based on ideas from the field of human-computer interaction, but adopts the system perspective (Snook, 2000) and the concept of vulnerability (Wackers, 2006) from the field of science, society and technology studies (STS). The main argument in this thesis is that the concept of vulnerability can fruitfully be studied from the 'subtask perspective' created. While a system's vulnerability refers to the state the system is in, the usability of a system's subtasks refers to the systems ability to perform reliably.

Key words: Human-computer interaction, usability, vulnerability, radiotherapy

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1. Introduction

In spite of all the efforts made to create safe technological systems, accidents happen. An often seen response after a large accident in complex systems, like nuclear power plants or transport systems is to create more rules and control (Cockelbergh & Wackers, forthcoming). Behind responses like these, you often find the perception of humans as the source of failures, and by reducing and controlling that source systems get safer (Dekker, 2006). After an accident a normal response is to search for who or what to blame. Newspaper articles covering large accidents often attribute the immediate cause of the accident to human failure. One clear example is the title of an article covering the Transrapid train accident in Germany September 23, 2006 (Fosse, 2006). The tile of the article was “Human failure caused the super-train collision”. A more thorough analysis of accidents like this, often change the attributed cause to be of a more complex and interrelated character.

Another example where the causes of accidents have been attributed to human errors is within healthcare, and the use of complex medical equipment. The number of patient injuries attributed to human errors is huge, and as a response there is an increased focus on how to reduce these kinds of accidents. One solution that has received a lot of attention is to improve the usability of medical equipment (Liljegren, 2006; Wiklund & Wilcox, 2005). Improving the usability of an interface often implies making the interface fit better with the capabilities and shortcomings of humans (Salvendy, 2006; Nardi, 1996). The idea is that if the user interface is designed to better fit humans, the interaction between humans and the equipment at hand will improve, and the number of errors will decrease (Liljgren, 2006).

Improving the usability of a user interface, or increasing the use of rules and control is common strategies to reduce the number and extent of human errors. As multidisciplinary and thorough analyses of different accidents have shown, attributing the cause of the accident to a human error, or any other isolated or localised cause, is to narrow. It will not give the correct answer to what went wrong (Dekker, 2006). A research field that study technological systems and the vulnerability of these kinds of systems are science, technology, and society studies (STS). Within this field, the concept of vulnerability refers to the state of being vulnerable[1] (Bijker, 2006). With a multidisciplinary agenda, scholars within this field show the importance of analysing accidents in technological systems from different levels (Bijker, 2006). One fruitful way of analysing these kinds of system failures can be to "detect the interaction of an unintended event with specific system vulnerabilities that were retained within the system or developed over time without properly being recognized and acted upon" (Wackers, 2006). When complex systems are developed or are in operational practice, different efforts are made to make the systems as safe and reliable as possible. But, as history show, despite these efforts, accidents happen.

1.1. Sketching out a new perspective - analysing system vulnerability

As systems gets more and more complex, accident analyses show that these kind of systems experience vulnerability (Bijker, 2006). The main topic discussed in this thesis is connected to the problem with detecting and acting upon the vulnerabilities that arise due to internal mechanisms in complex systems over time. As a possible tool to help handle these kinds of problems, I will in the following sketch out a new perspective, 'the subtask perspective', which I believe can help increase the awareness of, and handle vulnerability in complex systems.

1 In contrast to the concept of risk, vulnerability is a state. Vulnerability is a risk modifier.

1.2. Research question

Within the field of human-computer interaction, the concept of usability is applied as a quality attribute of a user interface. The usability of an interface is often associated with the ease a user can interact with the computer or the computer based tool. Inspired by the field of human-computer interaction, I will use this field as the starting point for my new perspective. This choice will be further elaborated in chapter two, where I also argue why I believe the field of human-computer interaction is too narrow and would benefit to increase their focus on safety. From the field of human-computer interaction the focus on interfaces and the concept usability are transferred to the perspective sketched out in this thesis. I will in this thesis try to answer the following research question: How can the concept of usability be transferred, to go beyond the limitations of the way it is used in the field of human-computer interaction, to a perspective focusing on system safety and reliable performance?

The concepts used in this thesis will be further described and developed through the different chapters, but I will briefly clarify some of the key terms through a short presentation of the organisation where I did my research.

I have gathered the empirical data for this thesis at the MAASTRO clinic located in Maastricht. The clinic's main task was to treat cancer patients with radiotherapy. This task can be further divided into three subtasks. First the patient had to go through a CT scanning. This scanning made the clinic able to localise the tumour inside the patient's body. The second subtask performed by the clinic was the planning of the treatment. In this subtask, the results from the CT were used to create a treatment plan for the patient. The third and final subtask was the actual treatment, where the patient was treated with radiotherapy. The clinic and the task it performed will be further presented later in chapter three. The 'subtask perspective' sketched out in this thesis will focus on, as exemplified above, the subtasks of a system.

The Therac-25

During 1985 and 1987, a computerized radiotherapy machine called the Therac-25 overdosed six patients (Levenson & Turner, 1993). The overdoses resulted in serious injuries and deaths. Even though these accidents were not formally investigated, they received a lot of attention from the popular press, and the accidents has been stated to be one of the most serious computer related accidents in history. The cause of the accidents has been identified as software failure, but due to the complexity of the system and the different interactions between components and activities, one can not attribute the accidents to a single cause. Many interrelated factors contributed to the accidents. Both the reuse of some elements from earlier models, replacing hardware-based safety checks and interlocks with software-based safety checks were among the elements that led to the accidents. In addition, there was no informative communication between the Therac-25 and the operators, and since the manufacturer had told the operators that the Therac-25 could not make mistakes, the accidents were not discovered right away.

Text box 1: The Therac-25

1.3. Theory and methodology

In the 1970's and 1980's, a new way of studying technology evolved within the field of STS. This new type of technology studies was characterised by three different trends. These trends can be summed up as following: ”Authors have been concerned with moving away from the individual inventor (or “genius”) as the central explanatory concept, from technological determinism, and from political aspects of technological development” (Bijker, *et al.,* 1987, p. 3).

The focus within the field of STS has developed over the years. In the 1970's and 1980's, the study of technological artefacts dominated the field. The main focus was the development of technology, and how it was shaped by the surrounding society. The scholars opened the "black box" of technology. One example is the thorough study of the construction of the bike (Bijker, 1995). In the 1990's the scope broadened "to also address social, political, and cultural issues of societal relevance" (Bijker, 2006). One important argument within STS is that "All relations should be seen as both social and technical…" (Law & Bijker, 1992, p. 290).

In his article "The Vulnerability of Technological Culture" Wiebe Bijker (2006) sets the agenda for why scholars within the field of STS should not only focus on the development of technology, but also technology in use. The vulnerability of our culture, or what Bijker calls the technological culture, is a result of the technological development in our society (Ibid.). The fact that we live in a technological culture makes us vulnerable, and it is therefore a necessity to study that vulnerability. "I will argue that it is worth to investigate the vulnerability of technological culture" (Bijker, 2006, p. 1). I will pace myself within this part of the field of STS, and focus on the use of technology, technology in action. Doing so, I will base my thesis on theories within the field of STS focusing on the concept of vulnerability. "These vulnerabilities can arise in system design, in maintenance regimes, in operational practices or in the planning and execution of modification programs" (Wackers, 2006, p. 1). I will, as within the field of STS look at the heterogeneity of technological systems, and look at both the social and technological factors that affect these kinds of systems. The field of STS will be a resource for my thesis, and the perspective I am sketching out here. Based on my background from computer science, and the field of human-computer interaction, I will place my thesis in the intersection between the field of STS and the field of human-computer interaction. The perspective sketched out here starts off in the field of human-computer interaction, but only some of the core elements are transferred to my new perspective. Focusing on the two concepts usability and vulnerability, I want to look at how these concepts relates to each other, and how the concept of usability can be transferred to correspond to the concept of vulnerability.

There is a lot of interesting literature within the field of STS of research covering the concept of vulnerability. Snook's case study of the shoot-down of two U.S. Army helicopters is one clear example. Other examples are John Law's (forthcoming) description of the London train accident, Wackers & Kørte's (2003) case study of the helicopter accident in the North Sea, Dian Vaughan's (1996) analysis of the Challenger accident, and Lundestad & Hommels (forthcoming) article on software vulnerability. The work by these scholars shows the complexity of the concept vulnerability. One clear similarity between the examples mentioned above is that they focus on systems in action. Compared to these accident analyses, I will not analyse an accident in this thesis, but focus on how system's, through the perspective sketched out here, can try to improve their ability to perform reliably. I will also look at how system's can increase its awareness of the state it is in.

As mentioned above, I will in this thesis look at the concepts of usability and vulnerability, and try to show why system safety/reliability can benefit from applying the concept of usability to the connection between subtasks in a system. My goal is to sketch out a new perspective that can help systems detect and handle vulnerability. I also want to increase the awareness of system vulnerability, to emphasise how vulnerability can arise, and to argue why I believe good usability of the interaction between subtasks can help improve safety. I know that the task I have given myself is rather tentative for the scope of this thesis, but as an answer to Wiebe Bijker's request for more research on vulnerability within the field of STS I believe that this thesis is a, though small, contribution.

To be able to answer the research question in this thesis, I have used the qualitative method, case study, where I have gathered a great deal of information on one case, the MAASTRO clinic. According to John Gerring (2004, p 341) the case study approach fits well with the attempt to study a single unit, and then trying to “generalise across a larger set of units”. My empirical data is basically gathered through semi-structures interviews. I chose this way of interviewing because I wanted to predefine the topics and some of the questions asked, but I did not want to control the interviews too much. I taped all my interviews to make sure that I had permanent records of all that had been said, but also because I wanted to be able to fully concentrate on the interview itself (Robson, 2002). I was also given the opportunity to watch the treatment of a few patients, which helped me understand the process of giving radiotherapy. It also increased my ability to identify the subtasks of the clinic. I have based my theoretical foundation on literature within the field of human-computer interaction and, as mentioned above, on literature on vulnerability, basically from the field of STS.

In my analysis, I have used the MAASTRO clinic and the empirical data gathered there to transfer the concept of usability to the 'subtask perspective'. The perspective itself were also developed through my analysis of the limitations within the field of human-computer interaction, research on vulnerability, and the data gathered through my interviews at the MAASTRO clinic.

I approached the MAASTRO clinic because of their position as a leading institute within radiotherapy. When I first approached them, I did not know they were moving, but I believe that the move, and the vulnerable state the clinic entered, contributed a lot to my research. Based on my empirical data, I am in no condition to evaluate the vulnerability of the MAASTRO clinic per se, but I will comment on possible sources to the system's vulnerability.

I did six interviews at the MAASTRO clinic, one with the manager of patient safety, and five with radiation technologists[2]. The reason why I choose to focus on the role of the radiation technologists was that they were involved in the whole process of treating cancer patients with radiotherapy. The radiation technologists interviewed, were a rather homogeneous group. They were all educated as radiation technologist, and their experience within the field of radiotherapy spanned from four to ten years. In connection with the move from Heerlen to Maastricht, the clinic had also changed the machines they used in radiotherapy. The people I interviewed had quite differing experience with this new equipment. Some of them had been part of a test team that started with these machines a year prior to the move, and others had only a few days of experience. The manager of patient safety gave me valuable information about the clinic, and acted as my access point to the clinic. I got most of interviewee appointments through her.

In this thesis, I will focus on some of the topics and issues discussed in literature covering vulnerability that I have felt could help create the 'subtask perspective' and that also could, in one way or another, be applied to the MAASTRO clinic. Because the MAASTRO clinic had a large focus on patient safety, some of the issues discussed in this thesis are therefore presented in a positive tone related to the clinic.

1.4. The structure of this thesis

Chapter 2: In this chapter I will present the field of human-computer interaction and the traditional way of defining and using the concept of usability. I will argue why I believe the

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[2] Website: Radiation technologist = operate radiographic and radiation therapy equipment to administer radiation treatment and produce images of body structures for the diagnosis and treatment of injury and disease. http://www23.hrdc-drhc.gc.ca/2001/e/groups/3215.shtml, visited September 2, 2006

field of human-computer interaction is too narrow, and why I believe the concept of usability should be closer connected to safety and reliability. I will also show how the field of human-computer interaction fruitfully can be the starting point for a new perspective, the 'subtask perspective'. The 'subtask perspective' focuses on analysing subtasks from different levels of aggregation. One of my arguments is that reliable performance is closely related to the integration of these subtasks. The concept of usability is transferred to the 'subtask perspective' as a quality attribute, but compared to the field of human-computer interaction, it is much closer related to safety and reliability. The concept of usability used in this thesis, can be divided into the attributes ‘visible’ and ‘well articulated’.

Chapter 3: I have done my research at the MAASTRO clinic in Maastricht, and will introduce the clinic and the work done at the clinic in this chapter. I will present the main subtasks of the system, and continue to develop my 'subtask perspective' with the empirical findings from the clinic.

Chapter 4: In this chapter I will present my main arguments for why I have sketched out the ‘subtask perspective’ in this thesis. Based on my empirical findings, I will argue why I believe that a 'subtask perspective' can benefit the systems ability to detect and handle vulnerability. I will focus on the concept of uncoupling, and the effect rules and regulations can have on the vulnerability of a system. The usability attribute ‘well articulated’ will also be discussed.

Chapter 5: I will in this chapter continue to transfer the concept of usability to my 'subtask perspective'. I will mainly focus on the quality attribute of ‘visibility’, since the attribute of ‘well articulated’ has been presented earlier. Usability, in this thesis, is seen as a concept describing the quality of subtask articulation and 'articulation zones'. If the different subtasks are not well articulated, the system is not able to perform reliably, and the vulnerability of the system might increase. The visibility of subtask articulation is closely connected to the system's ability to detect arising vulnerability.

Chapter 6: Conclusion. Due to the increased complexity in systems like healthcare clinics, there is a need to focus on vulnerability of those systems. Improving a system's ability to monitor and handle vulnerability might also make them able to increase the reliability and robustness of their system. The 'subtask perspective' sketched out in this thesis is a step in the right direction. Applying the concept of usability to subtask articulation, show that the relation between usability and vulnerability is of opposite character. While vulnerability refers to a system's state usability is connected to the quality of that state. To some point one can say that the two concepts are, as used in the 'subtask perspective' contradictory.

2. Usability and vulnerability

In this chapter I will present the field of human-computer interaction and the traditional way of using the concept of usability. I will argue why I believe the field of human-computer interaction should increase the focus on safety, and that their focus on human errors is to narrow. I will also show why and how the field creates the starting point of my new perspective. I will argue for why I believe there is a need for a new perspective focusing on the vulnerability of complex systems. Based on a system perspective, and inspired by the field of human-computer interaction, I am going to try to sketch out a new 'subtask perspective'. I will argue why I believe a perspective like this can help monitor, detect, and keep track of vulnerabilities in complex systems. With this new perspective, I also aim at increasing the general awareness of the concept of vulnerability and the effect it might have on complex systems.

Analysing how safety is handled in complex systems, often reveal several independent safety measurements. One example is the integration of rules and regulations. Another is the use of different kinds of risk management tools. Even though these safety measurements can be effective on their own, they do not always show, or are able to handle the state the whole system is in. The perspective sketched out here has the intention of helping systems get a more holistic view of the state they are in.

2.1. Redefining the concept of usability; taking a system perspective

2.1.1. Human-computer interaction

In the field of human-computer interaction, the core interest is, as the name implies, in the relationship between users and computers. The field has a human-centred focus to the development and use of computer based equipment. One way to define the field of human-computer interaction (abbreviated HCI) is to say that: "The field of HCI attempts to understand and shape the way people interact with computers" (Te'eni, Carey & Zhang, 2007). Bonnie Nardi (1996), an anthropologist focusing on human-computer interaction, sums the field up by implying that software designers use, broadly speaking, human-computer interaction experts to help them design better and more usable interfaces. The field of human-computer interaction emerged as a result of the computer being introduced to more and more people. In the 1970's, as the use of software increased, the need to focus on the user interface design became clear (Rosson & Carroll, 2002). Within the field of human-computer interaction, there is an ongoing debate about the best way to study and understand the way humans work. Traditionally cognitive science has been the most central theoretical framework connected to human- computer interaction, but today many theorists within this field state that it does not cover the whole concept of humans interacting with computers, and that the focus on human cognition is too dominant (Nardi, 1996). One of the main reasons for this critique is the lack of focus on the context where work takes place. In addition, the traditional field of human-computer interaction does not consider the historical developments of a system and the people that work within that system. The way people work is not static, it is continually changing (Ibid.). I will in section 2.1.2. present activity theory, a theoretical framework that suggests how the field of human-computer interaction can overcome their shortcomings.

As stated above, the main focus within the field of human-computer interaction has been to make the interaction between humans and computers better. System safety has not been a topic well covered in human-computer interaction literature (Rosson & Carroll, 2002). Traditionally, the topic within this field closest connected to safety is the concept of usability, and its focus on, among others, reducing human errors. Rosson & Carroll (2002), two scholars within the field of human-computer interaction, move a bit further and emphasise that usability is not only a concept covering something positive. The usability of an interface can also be a factor in workplace injuries and other safety-related hazards. This implies that the usability does not always have to be good; an interface can also have bad usability. The concept of usability refers to a continuum, not a predefined standard. They continue by stating that "...safety must be archived through a comprehensive process in which risks are documented and actively and persistently monitored throughout design, development, and deployment" (Rosson & Carroll, 2002, p. 354). As this quote shows, there is room for safety in the field of human-computer interaction. I will adapt the fact that safety needs to be handled during design, development, and deployment, but I will move a bit further, and focus on safety in system performance.

2.1.2. Human-computer interaction and activity theory

The theoretical field called activity theory is one of the fields that has criticized the field of human-computer interaction for not being complete. Activity theory has not only criticized the field for not including the context, but also stated that the field of human-computer interaction lacks a theoretical framework. Their argument is that activity theory can fill the role as that framework (Kuttii, 1996).

Yrjö Engeström introduces activity theory as the: "...commonly accepted name for a line of theorizing and research initiated by the founders of the cultural-historical school of Russian psychology, L. S. Vygotsky, A. N. Leont'ev and A. R. Lura, in the 1920 and 1930s" (Engeström and Miettinen, 1999, p.1). Traditionally, activity theory has been applied to psychology of play, learning, cognition, and child development, but, although these issues are still central, activity theory is now also focusing on work activities and the implementation of new cultural tools such as computer technologies (Engeström and Miettinen, 1999, p. 2). Kari

Kuutti, a professor in human-computer interaction, broadly defines activity theory as"...a philosophical and cross-disciplinary framework for studying different forms of human practices as development processes, with both individual and social levels interlinked at the same time" (Kuttii, 1996, pp. 25). He continues by stating that an activity always takes place in a context, and that it is impossible to fully understand that activity without the context. The general concepts of activity theory are based on a set of principles that, more than being a theory makes up a general conceptual framework. The main principles include, among others, development and mediation. An activity is seen as dynamic and changing. Every activity develops continuously and has a history of its own. The development of an activity is not linear, but dynamic and discontinuous. Regarding the principle of mediation, activity theory states that human activity is mediated by artifacts in a broad sense. Bonnie Nardi defines artifacts to "...include instruments, signs, language, and machines" (Nardi, 1997, p. 75). The artifacts can both be internal, like heuristics, and external, like a pen or a hairbrush (Kaptelinin, 1997, p. 109). The artifacts themselves are created and transformed during the development of the activity, and they bring their culture or historical remains of their development process into it. Nardi states that "...all human experience is shaped by the tools and sign systems we use" (Nardi, 1997, p. 10). Even though activity theory clearly separates between humans and non-human objects, I will not do that in the perspective taken in this thesis. I believe that whether or not a subtask is performed by a person or a machine, the integration between the subtasks is equally important. As Thomas P. Hughes states: "An artifact – either physical or non physical – functioning as a component in a system interacts with other artifacts, all of which contribute directly or through other components to the common system goal" (Hughes, 1987, p 51).

Scholars within activity theory see the traditional use of cognitive science as too restrictive for making people able to understand the interaction between humans and computers (Nardi, 1996, p. 13). Nardi states that "There is a fundamental need for a theory of practice in human-computer interaction studies" (Nardi, 1996, p. xi). Kaptelinin (1996, p. 103) backs up her statement by emphasizing that:

> It is generally accepted that the lack of an adequate theory of human-computer interaction (HCI) is one of the most important reasons that progress in the field of HCI is relatively modest, compared with the rate of technological development. People coming to the field of HCI from different disciplines – psychology, computer science, graphical design, and others – have serious problems in coordinating and combining their efforts.

Nardi continues by stating that the difference between cognitive science and activity theory is that activity theory focuses on the study of practice. Cognitive science only focuses on cognition and the user experience (Ibid.). Rather than being a rejection of cognitive science, activity theory is more like an expansion of it.

2.1.3. Moving from an individual level to a system perspective

2.1.3.1. Starting on an individual level

As mentioned above, activity theory criticizes the field of human-computer interaction for lacking a fundamental framework, and argues why activity theory can fill the role as that framework. The critique centres on the fields lacking focus on the context where an activity takes place, and the rather narrow cognitive focus the field of human-computer interaction has. I will in the following section present, what activity theory includes in the basic structure of an activity, and use that structure as a starting point for the system perspective taken in this thesis.

On the individual level an activity consists of a subject and an object. Compared to my presentation of the field of human-computer interaction, these are the main elements of their theory, the human (subject) and the computer (object). In activity theory, on the other hand, they also include the concept of a tool. In this structure, the computer is the tool, and the object is the thing that is under transformation. As shown in figure 1, the tool has a central and mediating role in the activity (Kuutti, p. 20).

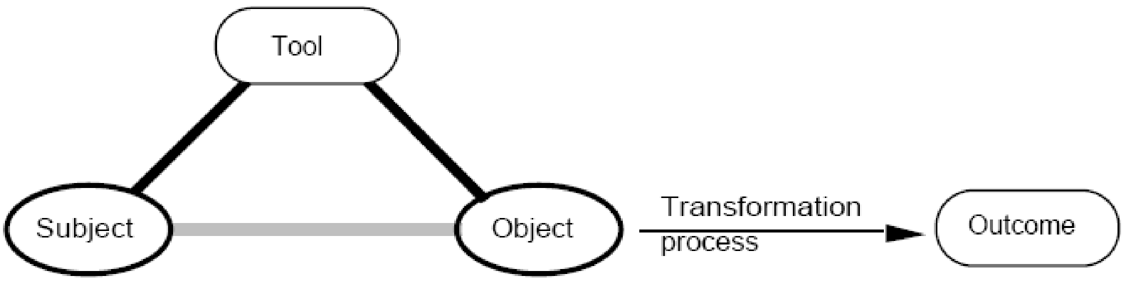

Figure 1: The individual level of an activity (Kuttii, 1997, p. 28).

But, as Kuutti (1996, p. 27) states, “This structure is too simple to fulfil the needs of a consideration of the systemic relations between an individual and his environment in an activity, however, and thus a third main component, namely community (those who share the same object) has to be added”.

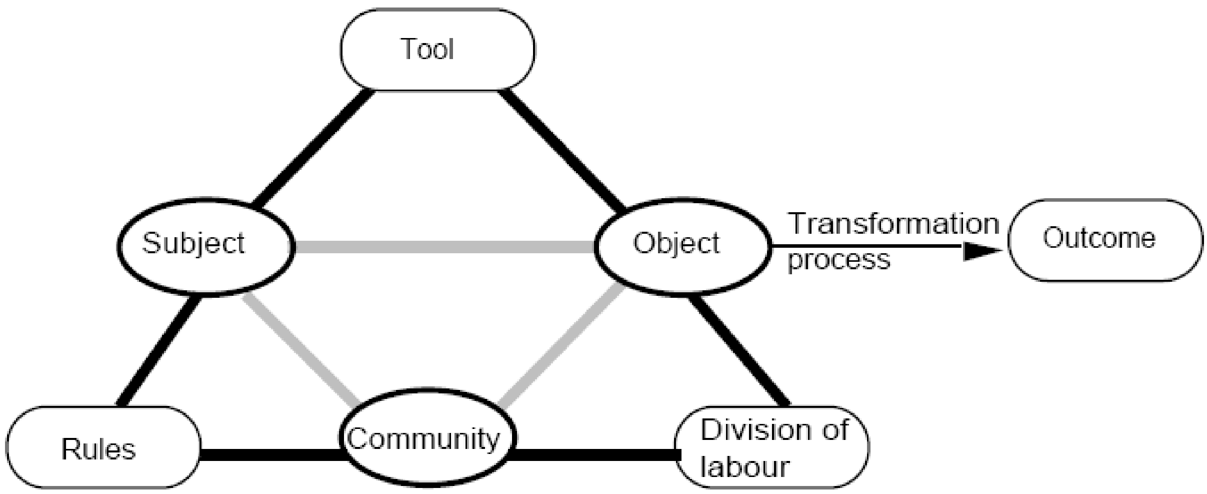

Figure 2: The basic structure of an activity (Kuttii, 1996, p. 28).

Figure 2 show how activity theory defines the basic structure of an activity. This structure is systemic, and all the elements are related to each other (Kuttii, 1997, p. 27). The context is added. Based on the systemic perspective taken by activity theory, and their critique of the cognitive focus in the field of human-computer interaction, I will move a bit further. I will not look at the different elements in an activity or a system per se, but take a system perspective and focus my analysis on the different subtasks that needs to be performed to complete the activity, or the main task the system has. I will use activity theory as my firs step towards the perspective created in this thesis.

To sum up my perspective so far, I will include the context where the actual work takes place, but at the same time move away from traditional cognitive view on humans as elements with limited abilities and as being prone to (human) error. The way activity theory looks at an activity as dynamic and developing will also create the basis for how I will view the state of a system in the perspective developed in this thesis. Moving towards theories covering complex systems, I will show that the perspective created here also differs a bit from activity theory.

2.1.3.2. A system perspective

Moving the focus to Charles Perrow's Normal Accident Theory (1999), I will continue to argue why I believe there is a need for this new perspective. Normal Accident Theory stems from a tradition of organisational theory covering accident analyses. Perrow takes a system perspective, and includes, like activity theory, the subject and the object into the unit of analysis (Figure 3).

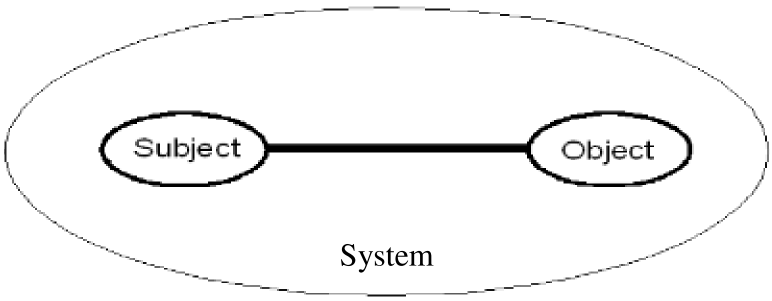

Figure 3: A system perspective.

But, there are some obvious differences between these two theories. When activity theory focuses on an activity, Perrow focuses on the properties of the system. The basic idea of his Normal Accident Theory is that interactively complex and tightly coupled technological systems are more risky than other systems. Due to the way these systems are constructed, accidents will happen; they are normal (Figure 4). Systems with these characteristics are bound to fail. An interactively complex system is a system with many interrelated subsystems. Two examples could be a university or an aircraft system. In Perrow's theory, the opposite of a complex system is a linear system. A typical linear system is an assembly line where you have to finish one step before starting another. When a system is tightly coupled, there is no room for slacks or processing delays. The operations of those kinds of systems rely on stable and punctual operation. An example of a tightly coupled system is rail transport, or a nuclear power plant. An example of a system that is both complex and tightly coupled is as shown in figure 4, a nuclear power plant.

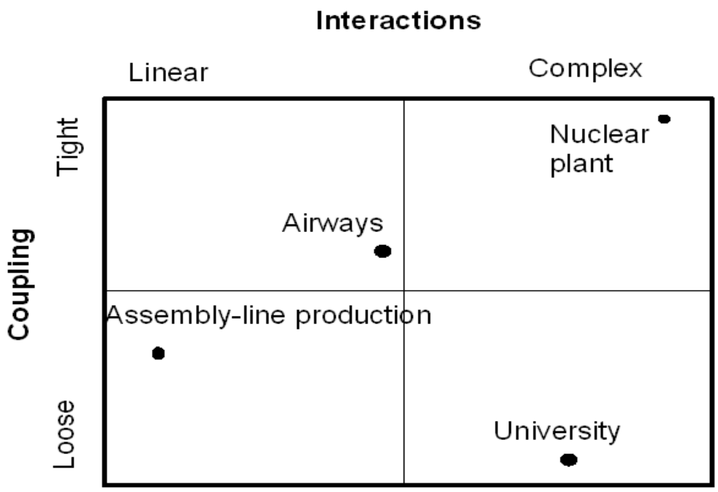

Figure 4: An excerpt of Perrow's interaction/coupling chart (Perrow, 1999, p. 97)

As opposed to the cognitive way of defining errors as human errors, as often done within the field of human-computer interaction, Perrow moves the focus to the properties of the system, and uses the term system failure (Ibid.). I will look closer at system failures later in this thesis.

Perrow's Normal Accident Theory has been criticized for being too static. It does not include the systems historical development. Arguing that systems that are complex and tightly coupled are bound to fail is very pessimistic. He does not present any suggestions on how to make these kinds of systems safer. Due to his pessimistic and static view, I will also include another scholar, Scott A. Snook. Snook (2000) combines Perrow's normal accident theory with high reliability theory, and ends up with a much more dynamic view of risks and vulnerability (Lundestad & Hommels, 2006). In his book, “Friendly Fire” (2000), he gives a thorough analysis of the accidental shootdown of two U.S. army helicopters over Iraq in 1994. In his analysis, Snook unravels why the military organization failed to identify the two helicopters as friendly. His theory of practical drift describes “the slow [and] steady uncoupling of practice from written procedure” (Snook, 2002, p.194). Over a time period, the people working in the system developed more practical ways of working. And in that process, they slowly drifted away from the written procedure implemented in the system. Due to the drift towards more practical ways of working, the military organization did not manage to detect the helicopters as friendly. The system failed (Ibid.).

2.1.4. Creating a new perspective, a subtask perspective

Inspired by these different theories, I am now able to sum up my arguments, and present the sketch of my perspective. Moving away from the field of human-computer interaction, I am inspired by their focus on the interaction between humans and computers, and will transfer this concept to my system perspective. From activity theory, I transfer the way they study an activity to my study of a system performing a main task. Instead of focusing on the different basic concepts of an activity, I will focus on the different subtasks a system needs to perform to complete their main task. As within activity theory, I also believe that subtasks are dynamic, and constantly evolving and developing. I will do my analysis from a system perspective, and make the system's subtasks the focus of study. My main argument is that for a system to be able to perform its main task, a number of different subtasks need to be completed. To be able to perform safe and reliable, these different subtasks need to be well integrated, or articulated.

Within the traditional cognitive view, human-computer interaction systems consist of two information processing units. The units are the human being and the computer. The output from one unit is the input to the other (Kaptelinin, 1997, p. 105). I will move away from the traditional view of an interface, like the user interfaces studied in the field of human-computer interaction, and use the concept of an interface to describe a link between two subtasks. The link does not have to be anything physical, but only describe things that interact in one way or another. To be more precise, I will move away from the user interface, and focus on the interfaces between the subtasks of a system. I will use the concept of a subtask to describe a unit of processing, performed by a person, a machine, a software program, or other. I do not want to make a more exact definition of a subtask, because I want too keep my perspective dynamic, and able to adapt to different kinds of systems. Instead, I will give some examples from the unit of analysis in this thesis, the MAASTRO clinic.

The ‘subtask perspective’ can be applied on different levels of aggregation, depending on where in a system the analysis is done. As mentioned in the introduction, the main task of the MAASTRO clinic was to treat patients with radiotherapy. The clinic can, on a ‘global’ level of aggregation be further divided into three subsidiary subtasks: the CT scanning, the planning and the actual treatment. These subsidiary subtasks can again, on different levels of aggregation, be divided into an unknown number of different subtasks the clinic has to perform to be able to perform its main task. An example of a subtask on a more ‘individual’ level of aggregation is patient identification. After one of the operators has fetched the patient information from the database, another operator checks whether or not the subtask of fetching patient information has returned the correct patient, the patient in the treatment room. The operator asks the patient for his or her name and birthday. After the patient has replied, the operator checks the answer with the information returned by the first subtask.

Another example of a subtask is placing a patient on the treatment table. The operator places the patient according to marks drawn on the patient’s body. After the patient is placed, the software connected to the accelerator performs another subtask, and checks if the table is in the position planned for this patient. If the position of the treatment table and the position planned for the treatment differ, the system informs the operator that the system will not radiate. If the operator still wants to radiate, a third subtask is performed. The operator then has to overwrite the system. I have no intention of defining every subtask of the MAASTRO clinic. My main goal is to underline why I believe monitoring and analysing subtasks can improve a systems ability to handle vulnerability.

The subtasks of a system are connected to each other in different ways. I will in the following use the word articulated instead of the term connected. By using the word articulated, I move away from the linguistic meaning of the word, and focus more on its general meaning. The linguistic meaning of articulation is to express verbally. The more general meaning is connected to making something explicit. I will use the term articulation to describe the situation of joining together, like the joints in a person's body. In this sense, to articulate with something, means to make a connection. I will in the following chapters exemplify this statement.

In my subtask perspective, an interface is, as mentioned above, the site where subtasks articulate. Compared to how an interface is defined in the field of human-computer interaction, the interface here is a bit more blurry. I still believe that it is important to identify it as a kind of interface because I believe that it is, among others, the quality of these interfaces that determine the system's ability to recognise and resist vulnerability. I also want to move a way from the definition of an interface used in human-computer interaction because it does not include the developmental changes over time that a subtask, and subtask articulation goes through.

To move away from the more clear cut and robust definition of an interface, as something that exists, something you can see and touch, I will use the term 'articulation zone' to describe the interfaces where subtasks interact, are articulated, see figure 5. As my short presentation of the MAASTRO clinic in chapter one described, the work connected to treating patients with radiotherapy can, on a ‘global’ level of aggregation, be divided into three subtasks, CT scanning, treatment planning and the actual treatment.

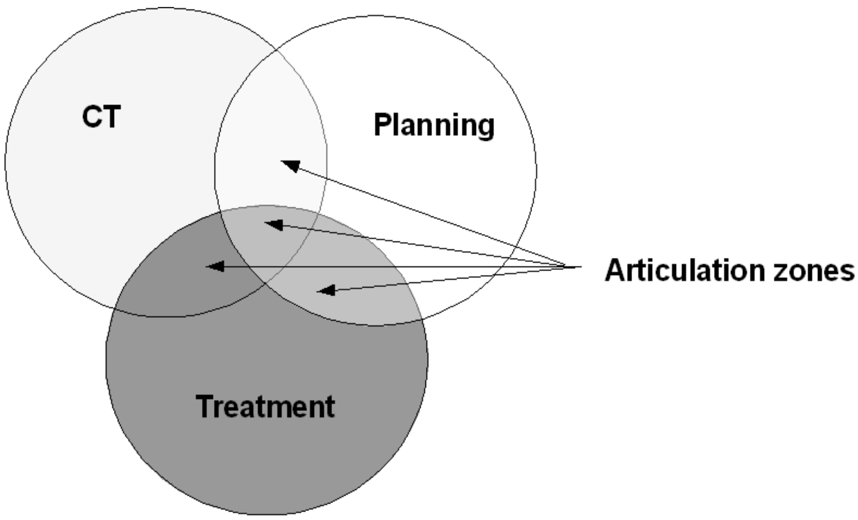

Figure 5: The ‘global’ level of aggregation, the articulation zones in the MAASTRO clinic

Figure five illustrates the subtasks and the 'articulation zones' on the ‘global’ level of aggregation. The figure shows the different subtasks, and the fact that the different subtasks articulate with each other. It also shows that the 'articulation zones' are very dependent on the quality and accuracy of that articulation. As I will describe more in chapter four, system vulnerability can arise if these subtasks are not well articulated.

In contrast to figure five, figure six show subtask articulation and 'articulation zones' on an ‘individual’ level. As mentioned above, before a patient is treated, the operator fetches the patient information and the treatment plan from LANTIS, the database storing all the patient information. They have to check whether or not they have the right patient, they have to place the patient, and finally they treat the patient. This is a simplified description of the subtasks involved on this level of aggregation, but it helps visualise subtask articulation and the 'articulation zones'.

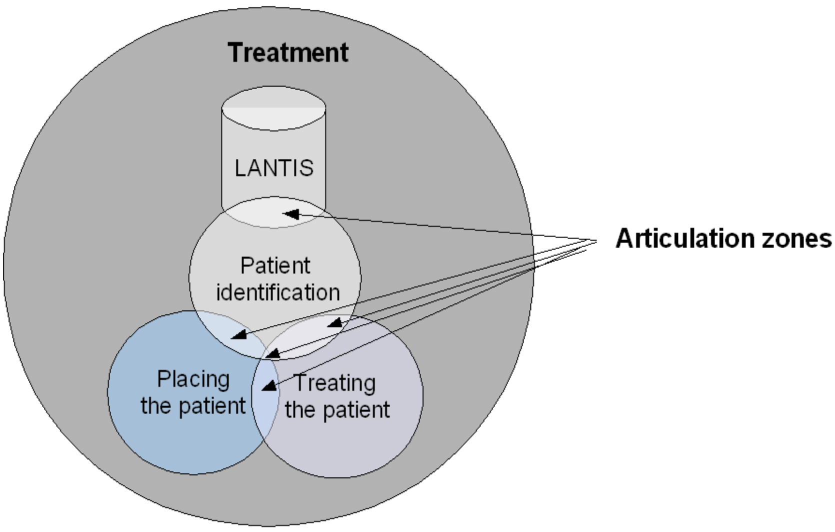

Figure 6: The “individual” level of aggregation and its articulation zones.

The MAASTRO clinic can also be analysed from other levels of aggregation. The MAASTRO clinic was a part of the academic hospital in Maastricht, so analysing it from that level of aggregation is one solution, regional and national levels are also good examples.

2.1.5. Usability

Usability is a concept normally related to the field of human-computer interaction (Te’eni, Carey & Zhang, 2007). There are a few different definitions of usability, and these different definitions vary a bit. An overall agreement is that usability has to do with how easy people can use a particular object to reach a particular goal. How easy it is to use a website, or how easy it is to buy a ticket from the ticket machine at the train station, can be evaluated through the object's usability. ISO 9241-11 (1998) Guidance on Usability issued by the International Organization for Standardization defines usability as: "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"[3]. This definition refers to the product, the user, the goal, the quality of the process, and the context of were it all takes place. Another way to define usability has been done by Jakob Nielsen. He divides the term usability into five associated usability attributes: learnability, efficiency, memorability, few errors and satisfaction (Nielsen, 1993). The usability attributes of learnability, memorability and few errors all have a cognitive base, they are clear examples of the cognitive focus within the field of human-computer interaction.

The main difference between these two definitions is that the first show the change called for earlier in this chapter, it is moving away from the traditional cognitive base. The definition includes the context where the interaction takes place. It also moves away from the cognitive based focus on humans as information possessors. This is a rather new, but important development in the field of human-computer interaction, and as I will show in the rest of this chapter, this is something I believe is very important. The second definition is more adjusted to measuring usability. It divides the concept of usability in to measurable attributes. Even though definitions of the term usability include the attributes of reducing human errors, working efficiently, and also the ability to recover from errors, I believe the focus is to narrow. The problem these definition has within the field of human-computer interaction today, is that even though many scholars base themselves on a definition like the

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3 Web site: http://en.wikipedia.org/wiki/Usability

first one presented here, the usability attributes presented in the second definition are often used to further divide the concept of usability into measurable attributes (Rosson & Carroll; Te'eni, *et al.*). This is an example of how the cognitive limitation of analysing the relation between humans and computers continues to be a huge part of the field of human-computer interaction. Complex systems, like the MAASTRO clinic, implement many different safety initiatives to make their performance more safe and reliable, but still accidents and failures happen. This leads me to one of my main arguments: There is a need to, especially in complex systems, increase the focus on reliable performance, safety and vulnerability of the system as a whole. I believe that this can, among others, be done through the perspective developed in this thesis. The perspective's main focus, as mentioned above, focus on the subtasks of a system, the way they are connected to each other, and the quality of that connection. Wackers and Kørte (2002, p. 4) underline why it is important to move away from the traditional way of defining human errors: "Like random technical failures, human errors as causes are themselves results of more profound mechanisms and processes".

The main difference between the way usability traditionally has been defined, and the way I will use it in this thesis, has to do with the level it is used on. Traditionally, usability is used on an individual level, describing the quality of a user interface of a computer. As shown later in this thesis, I will apply the concept of usability on different subtask levels. Compared to the way the field of human-computer interaction defines and uses the term usability, I will move quite far away from the quality attributes mentioned above, and connect usability closer to safety and reliability. I will further divide the concept of usability to include the attributes 'well articulated' and 'visible'. Compared to the traditional way of defining usability I will focus more on its connection to resilience, robustness, and reliability. For a system to have reliable performance, the subtasks need to be well articulated and sometimes also made more visible. My argument is that if subtasks are not well articulated, system vulnerability can arise. I also believe that the visibility, further discussed in chapter five, of subtask articulation affects the systems knowledge about the state it is in. To sum it up, the usability of a system says something about the quality of the articulation of the subtasks. Usability of articulations and 'articulation zones', is not only connected to the normal day to day operation, it is also closely connected to the occurrence of unanticipated or unexpected events.

2.1.6. Vulnerability

I will in this thesis focus on vulnerability due to internal mechanisms, and not as a result of external threats. The way I have defined usability above, is closely connected to how I will define vulnerability in this thesis:

> Vulnerability refers to a system's reduced ability to anticipate, resist, cope with, respond to or recover from undesired events that threaten the achievement or maintenance of performative closure. Performative closure is (shorthand for) the achievement and/or maintenance of core task completion while maintaining functional system integrity (Wackers, 2006, p. 1).

The reason why I decided to use this definition of vulnerability is the system perspective taken, and the fact that it is dynamic and has a positive undertone. By a positive undertone, I am, among others, referring to the term “reduced ability”. The system is not doomed to fail; things can be done to improve the system’s ability to respond to and to recover from undesired events. This is a clear contrast to Perrow's Normal Accident Theory presented earlier in this chapter. I also think that the definition shows the diversity and complexity of the concept vulnerability. Even more, the definition underlines the need to take a system perspective when analysing safety, and trying to improve system reliability and system safety. Its focus on the systems reduced ability to respond and recover also refers to the fact that system vulnerability can be invisible, not visible to the people or to the safety measurements implemented in the system. This is also why I believe that there is a need to focus on the usability of subtask articulation and 'articulation zones'. Increasing the awareness of how systems can enter a more vulnerable state might improve systems ability to both reduce this vulnerability and also to take action to reduce potential vulnerable states. The result might be that the system is able to enhance its robustness and resilience.

The MAASTRO clinic defined failures into three different categories: human failures, technical failures and organisational failures. The clinic worked hard to try to reduce the failures happening in the clinic. They admitted to mainly focusing on technological and organisational failures. Their argument was that human failures are always present, and that it was more difficult to do anything about them. Nielsen states that “[a] basic principle for user interface design should be to acknowledge that users will make errors no matter what else is done to improve the interface, and one should therefore make it as easy as possible to recover from these errors” (Nielsen, 1993, pp. 138-139). This quote, deeply rooted in the field of human-computer interaction, triggers one of my main arguments. Defining a failure as a human failure, or a human error is too narrow. As mentioned in chapter two, one of the attributes closely connected to the traditional way of using the concept of usability, is the desire to reduce the number of errors made by users. This statement is not meant as a rejection of the work done within the field of human-computer interaction, it is only meant as an argument for why I believe that the field needs to move away from the limited focus on human errors, and focus more on safety and reliability as a whole. This way of defining an error bears with it a clear cognitive based definition. An error is, or at least entails a cognitive error; a fault in the processing of information. Different scholars have devoted a lot of research to the concept of human errors, and one of them is James Reason. In his book “Human error” (1990), he emphasise the need to understand human errors when trying to improve system safety. He also states that to accept the phrase human error as an explanation instead of something that needs to be explained, is a fundamental attribution error (Reason, *et al.*, 2001). Instead of looking at human error as the cause of trouble, human error should be seen as a symptom of trouble deeper inside a system. One clear mistake is to seek the failure to try to explain it, one is not able to explain a failure by trying to find where people went wrong (Dekker, 2006). Many accident analyses (Vaughan (1996), Snook (2000), Wackers & Kørte (2003)) where the immediate reason for the accident could seem like a human error, have, after the analysis shown that the reason is much more complex and that it is deeply rooted in the system. The need too look deep and multidisciplinary into an accident is crucial for understanding why an accident happened (Bijker, 2006). I will not use the term human error in this thesis, because I believe that the concept bears with it too much history, and the concept immediately gives associations to the human as the one causing the accident.

2.2. Summary

To sum up the 'subtask perspective' sketched out in this chapter, I will divide it into three parts. First of all, a system has a main task. To be able to perform the main task, a number of different subtasks need to be performed. These subtasks can be viewed from different levels of aggregation depending on what you are looking for. The MAASTRO clinic has one main task: treating patients with radiotherapy, and, on the ‘global’ level, three subtasks: CT scanning, planning, and treatment. In addition it has a large number of subtasks on the ‘individual’ level. In this thesis, I will focus on both the ‘global’ level of aggregation, and the ‘individual’ level of aggregation. The second point I have made in this chapter, is that subtasks articulates with other subtasks, and the quality of this articulation is important for the system's ability to perform reliably. Since subtasks often articulate with more than one other subtask, I have introduced the term 'articulation zone' to describe the area where subtasks meet. Finally, I have transferred the concept of usability as a quality attribute of subtask articulation, referring to the way subtask articulation can affect system safety and system reliability. The concept usability is transferred to hold the two quality attributes ‘well articulated’ and ‘visible’.

Inspired by the field of human-computer interaction, I have created a sketch for a perspective called the 'subtask perspective'. I have argued why I think that the focus on reducing human errors by making the interface fit with the abilities and constrains humans have, are too narrow. I believe that analysing a system from the 'subtask perspective' can make systems better equipped to handle vulnerability. One of my main arguments is that this perspective focuses on internal mechanisms, and because it does not separate between different kinds of subtasks, it is able to monitor all kind of subtasks and arising vulnerabilities. I will in the next chapter give a more thorough presentation of the MAASTRO clinic, and the subtasks performed there.

3. The MAASTRO clinic, a complex system

I will in the following chapter introduce the MAASTRO clinic, and continue to develop and illustrate my subtask perspective. Applying a system perspective to the MAASTRO clinic makes the clinic the system. The main task of the system is treating cancer patients with radiotherapy, and the main components are the heterogeneous unit of humans and machines. The patients are at the same time part of the system, as long as they are scheduled for treatments, and entering and leaving the system each time they are scheduled for a treatment. The patients are still a part of the clinic even though their bodies are not present there. To be able to complete the system's main task, the whole process of treating patients with radiotherapy, the different subtasks have to be performed within the system. The way they work, how the different subtasks are articulated, and how the different subtasks affect each other and the system, will be presented in this chapter. I will in the following present the three subtasks on the 'global' level of aggregation, but my main focus on the last subtask, the actual treatment of patients, and the 'articulation zones' between the three subtasks (see figure 5 and 6).

3.1. The MAASTRO clinic, a presentation

The MAASTRO clinic[4] was originally founded in Heerlen in 1977. The foundation's main objective is to give care, in the broad sense, to oncology[5] patients. The foundation states that its main task is to give radiotherapy[6], but it also focuses on research, education and promoting

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4 Web site: www.maastro.nl, visited June 10, 2006

5 Web site: Oncology = the branch of medicine that deals with tumours, including study of their development, diagnosis, treatment, and prevention. http://www.ukhealthcare.uky.edu/patient/glossary/glossary-o.htm

6 Web site: radiotherapy = the use of high-energy radiation from x-rays, gamma rays, neutrons, and other sources to kill cancer cells and shrink tumours. http://www.seniormag.com/conditions/cancer/cancerglossary/r.htm, visited April 9, 2006.

regional and national health care policies. The foundation has a close connection to the University of Maastricht, and an annex of the MAASTRO clinic was built next to the Academical Hospital Maastricht and the medical faculty in 1996. Later, they decided to move all the therapeutic functions to Maastricht. May 8, 2006 was the date of the move, and the clinic entered their new facilities in Maastricht. According to Petra Reijnders-Thijssen[7], the Manager of patient safety at the MAASTRO clinic, radiotherapy is probably one of the fastest growing technologies in healthcare. She also stated that radiotherapy was dominated by a technology push both connected to the integration of information technology, but also because they try to reduce the human handling in the system. This topic will be further discussed in section 4.1.

Giving radiotherapy is not the only task done at the clinic, so the clinic is even more complex than presented here. Since this thesis focus on vulnerability, and a system's ability to recognise and handle vulnerability, I find it appropriate to comment that vulnerability does not only have to be seen as a negative factor. The link between innovation and vulnerability is evident. As Wiebe Bijker states, vulnerability is the price we must pay to be able to live in an innovative culture (Bijker, 2006). Because the MAASTRO clinic is innovative, they do, as a result of it, experience vulnerability. During my interviews, the interviewees were very attentive to the fact that their innovative style made them both participants in pioneering research and more vulnerable.

The following sections will both present subtasks on the 'global' and the 'individual' level of aggregation.

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7 Interview Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

3.1.1. The way they worked, the subtasks performed

3.1.1.1. The first main subtask; the CT

At the MAASTRO clinic, the process of giving radiotherapy was divided into three different subtasks[8]. After a patient had seen a physician, they were scheduled for computed tomography[9] (CT). A CT, in this setting, is a diagnostic support tool used for radiotherapy planning. Normally, two radiation technologists and the patient's physician were involved in this subtask. The CT consisted of a circle gantry and a table. Before the actual scanning, the subtask of placing the patient on the table was performed. The next subtask was initiated from the control room, and resulted in the subtask of the CT scanning the patient. The CT scanning implied making a cross-sectional image of the patient's body, or parts of the patient's body. The image created by the CT scanner helped the MAASTRO clinic calculate the size, shape and placement of the tumour. Knowing what the tumour looked like made them able to plan, more accurately, how to radiate it. This is an example of subtask articulation. The image from the CT was used in the planning of the treatment. The subtasks had to be well articulated because the result of this subtask was used in the next subtask. Failures happening in one subtask could get transferred to or otherwise affect the next. Lasers were installed on the wall next to, and on the ceiling above the CT. The lasers performed the subtask of showing horizontal and vertical lines on the patient, and the operators used these lines to mark the patient. The marks drawn on the patient worked as reference points, and guided the operators to where the tumour was located. To have accurate reference points were important, because the placing of the patient was crucial for the accuracy of the treatment. Since these marks

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8 Interview with Jeroen Baltussen, radiation technologist, MAASTRO clinic, June 2, 2006

9 Web site: http://www.medical.siemens.com/webapp/wcs/stores/servlet/ProductDisplay?catalogId=-11&catTree=100001,12781,12752*293590939&langId=-11&level=0&productId=142089&storeId=10001&view=clinical, visited July 26, 2006

were used by the operators when placing the patient on the treatment table before the actual treatment, the 'articulation zone' between the laser, the marking of the patient, and the placement of the patient needed to be well articulated.

I will present the subtask of placing the patient more thoroughly later in this chapter. The data produced during the CT scanning entered the system, and affected the succeeding subtasks. The 'articulation zone' between this subtask and the next subtask is, among others, the transfer of the data gathered from the CT to the planning system. The 'articulation zone' between this subtask and the subtask of treating the patient is also affected by the articulation of the subtasks, indirectly through the treatment plan, and directly by the accuracy of the marks on the patient (see figure 5). If the subtasks are not well articulated, they might affect the system's ability to perform reliably; vulnerability might arise.

3.1.1.2. The second main subtask; the planning

After a patient had been through the CT scanning, the information gathered was used in the second subtask on the ‘global level of aggregation, the planning of the treatment. The planning room was divided into different areas where the different parts, or subtasks, of the treatment plan were performed. The planning system was called XIO. Due to the fact that XIO needed a rather strong computer to be able to run, and that the software could not run on computers with Microsoft's Windows operating system installed, XIO had to be installed on separate computers. The subtasks performed during planning, were connected to the dosage, the treatment fields, and the shape of the treatment fields. A treatment field is the place on the body where the radiation beam is aimed[10]. To make sure that the treatment plan was correct, it

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[10] Website: http://www.cancer.gov/Templates/db_alpha.aspx?searchTxt=treatment+field&sgroup=Starts+with&_ctl0.x=8&_ctl0.y=1, visited September 20, 2006

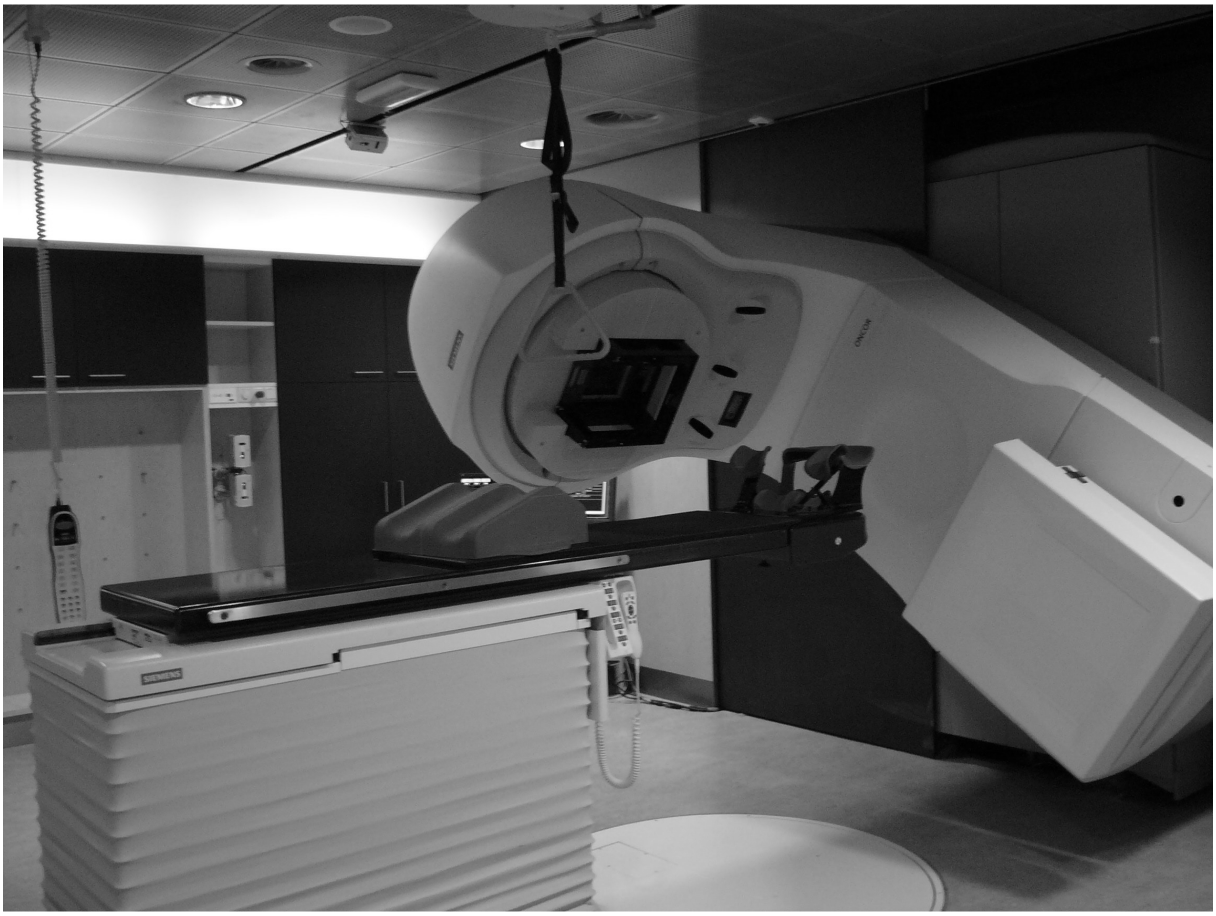
had to go through different subtasks of safety checks. For the treatment plan to be correct, the articulation between the different subtask checks had to be well articulated. If a mistake managed to pass one of the safety checks, the other checks needed to catch it in order for the system to be able to perform reliable. The interviewees reported that mistakes managed to get through all the safety checks. They could not specify why, but only commented that sometimes they managed to catch the mistake before the patient was treated. Other times, they did not detect the mistake until after the patient was treated, if the mistake was detected at all. The correctness of the treatment plan was crucial for the actual treatment. The manager of patient safety, Petra Reijnders-Thijssen, defined patient safety to be: “In the end, we want to have our patients through the treatment the way we wanted it to be from the preparation. That is patient safety”[11]. This shows how important the 'articulation zones' between the CT scanning, the planning and the actual treatment are. If the subtasks were not well articulated, the system was not able to perform reliable.

3.1.1.3. The third main subtask; the treatment

At their new location in Maastricht, the MAASTRO clinic had five Siemens ONCOR™ Linear Accelerators. A Linear accelerator is a machine that accelerates electrons to create high-energy beams that can destroy tumours with minimal effect on the surrounding healthy tissue (Leveson & Turner, 1993).

11 Interview Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

The linear accelerator was located in a treatment room, and was operated from a control room (See picture 1).



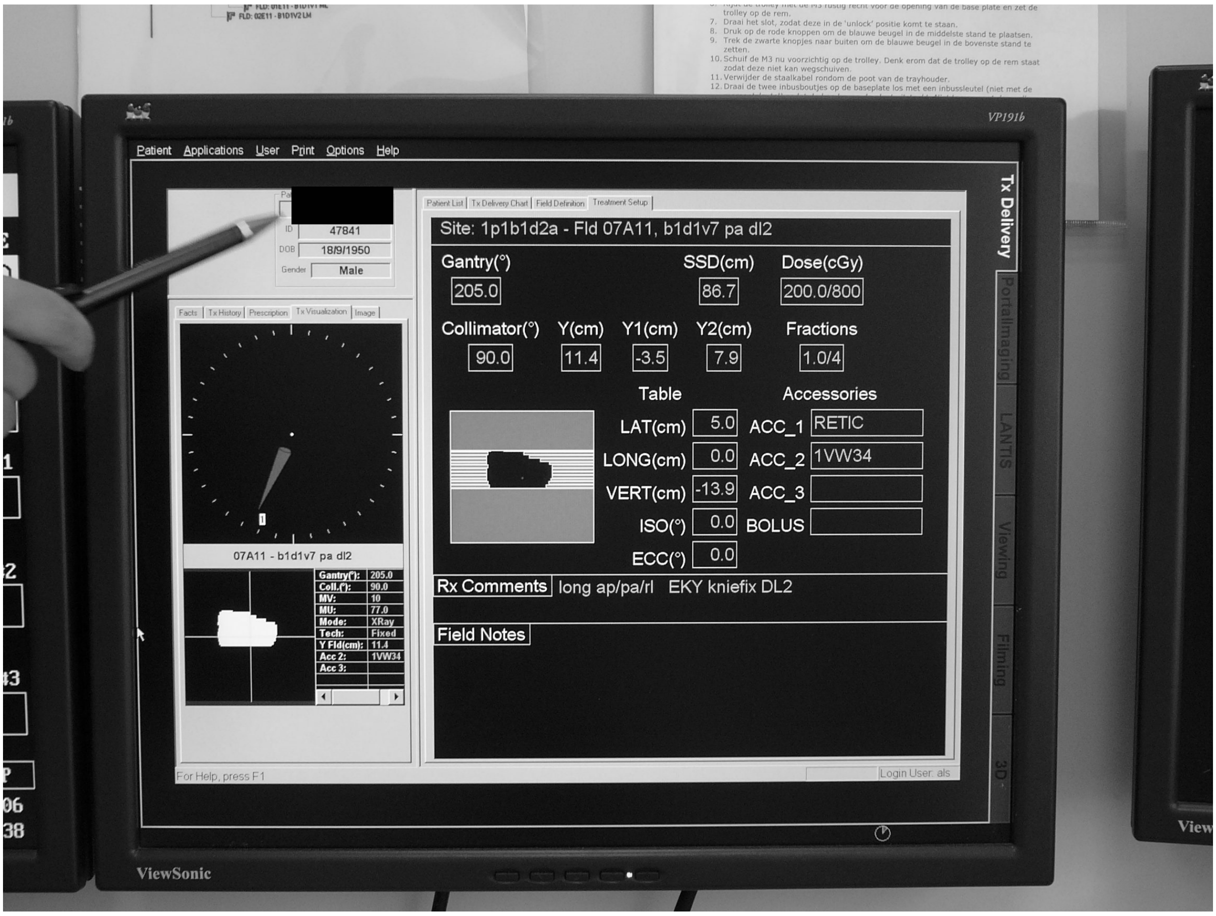
Picture 1: A linear accelerator located in one of the treatment rooms in the MAASTRO clinic

The linear accelerators at the MAASTRO clinic performed two main tasks: it treated the patient, and it checked whether or not the variables manually entered inside the treatment room corresponded with the variables from the treatment plan. These variables were connected to the position of the table, the position of the gantry, and so on. The control room was equipped with a computer that controlled the accelerator, computers running the different software installed at the clinic, and TV and audio surveillance of the treatment room. These different computer systems all performed different subtasks for the system to be able to perform its main task.

The computer controlling the accelerator gave, among others, the operators information about the accelerator, and whether it was ready to radiate or not, a subtask check (See picture 2). If not all the parameters were set correctly, the accelerator would not treat the patient.

Picture 2: The user interface of the computer controlling the linear accelerator.

Next to the computer controlling the linear accelerator, the operator room was equipped with a computer running COHERENCE Therapist Workspace (See picture 3). COHERENCE was a Siemens developed software system, and the software's main function, according to Siemens[12], was to optimise the workflow at the clinic.



Picture 3: The user interface of COHERENCE

COHERENCE made all the tools and data needed during treatment available for the operators, and made the subtasks performed by the operators easier and more efficient. The 'articulation zones' between the subtasks performed by operators and the subtasks performed

12 Web site: http://www.medical.siemens.com/webapp/wcs/stores/servlet/CategoryDisplay?productFamilyName=Oncology+Workspaces&storeId=10001&langId=-11&catalogId=-11&categoryId=15955&catTree=100001,12789,12757&level=0&pageName=Oncology+Workspaces, visited July 10, 2006

by the technical equipment included these screens. I will discuss these 'articulation zones' a bit further in chapter five.

To operate the linear accelerator, the radiation technologists worked in groups of three. For each patient, the operators rotated on the different roles. Two of the operators were responsible for placing the patient on the table in the treatment room. Placing the patient comprised of two subtasks. The two operators in the treatment room performed one subtask each. One placed the patient on the table, and the other placed the table in the correct position. In addition, the operator in the control room performed the subtask of watching and controlling the work done inside the treatment room on the monitor. The user interface of the screen controlling the linear accelerator showed the current and the planned position of the table, the gantry angle, the dosage and other kinds of information connected to the treatment of the patient. When all the parameters were set and verified, the two operators inside the treatment room went back into the control room. Then, if the machine said OK (subtask), and the operators agreed that everything was OK (subtask), the beam was sent to the accelerator (subtask) and the patient was treated (main task completed).

As described above, the work done inside the treatment room and the operator room consisted of many different subtasks. Some of the subtasks were of a more administrative character, others were directly connected to the treatment given to the patient. When a patient entered the treatment room, many subtasks had already been executed, and the result of those subtasks affected the treatment. These subtasks meet the subtasks of the treatment process in the 'articulation zone' between, among others, the data fetched from the system, and the variables set by the operators in the treatment room and the control room (see figure 5).

3.1.2. Increase patient safety through PRISMA and HFEMA.

The manager of patient safety, Reijnders-Thijssen[13] at the MAASTRO clinic reported that they had a large focus on patient safety. She said that the recent move form Heerlen to Maastricht had changed and increased the number of risks they experienced in their clinic. Before Reijnders-Thijssen started as manager of patient safety, she wrote a thesis for the MAASTRO clinic about analysing risks in radiation therapy. One of the reasons for the topic of her thesis was the already planned move from Heerlen to Maastricht. The thesis concluded with a recommendation to the clinic to implement two software tools, and as Reijders-Thijssen reported, “the tools are used, at this moment, to get this organisation safer than before”[14]. The two tools were called the PRISMA (Prevention Recovery and Information System) tool and the HFEMA (Healthcare Failure Mode Effect Analysis) tool. PRISMA was a reporting tool and HFEMA was a risk predictive analysing method. Using these tools increased the MAASTRO clinic's ability to surveillance their own subtasks. As the manager of patient safety reported, they used the PRISMA tool to detect process deviation. Compared to the way I have used the term subtasks in this thesis, process deviation can either mean that the subtasks were not well articulated, or that a subtask was not reliable in its self. By analysing the way they work through these tools, the MAASTRO clinic kept a constant eye on the way they work, and the reliability of the way they work.

3.2. Summary

In chapter three, I have presented the MAASTRO clinic, the clinic’s main task, and some of the subtasks performed there. I have used this chapter to further develop my 'subtask

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13 Interview with Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

14 Ibid.

perspective', and to exemplify what I mean with a subtask, subtask articulation and 'articulation zones'.

The main components of the MAASTRO clinic are the operators, the radiation technologists working in the MAASTRO clinic, and the different tools used for the system to be able to perform its main task. The number of subtasks that has to be performed by the system is large and varied. Some of the subtasks are directly connected to the actual treatment of patients, others are more administrative tasks, and some are connected to safety and the reliable performance of the whole clinic. I have briefly commented on the quality of subtask articulation, the usability of the articulation and the ‘articulation zones’. The MAASTRO clinic had a large focus on safety, and had implemented different tools and elements to become safer.

In the following chapter, I will argue why I believe the 'subtask perspective' can improve a system's ability to detect and handle vulnerability.

4. Why analyse systems from a 'subtask perspective'?

In the chapter that follows, I will use the MAASTRO clinic, and its subtasks to look closer at how and why vulnerability can enter the system even though massive safety measures are taken to keep this from happening. I will try to underline why I believe analysing subtasks, and subtask articulation through this 'subtask perspective', can help systems handle vulnerability.

First, I would like to move the focus back to the definition of vulnerability used in this thesis: "Vulnerability refers to a system's reduced ability to anticipate, resist, cope with, respond to or recover from undesired events that threaten the achievement or maintenance of performative closure" (Wackers, 2006, p. 1). I will base these next chapters on how I believe analysing and monitoring subtask articulation can have a positive effect on system vulnerability, and improving the systems ability to achieve performative closure. I will look at how subtask articulation can help systems perform reliably, and also how subtasks and the lack of subtask articulation can make vulnerability arise in the system. The main reason why I believe it is important to understand the vulnerability of a system is to reduce the chance of the undesired events that threaten the system's ability to perform its main task. The main topics of this chapter are the concept of uncoupling, drift, the increased use of computer based tools, and the role of rules and regulations. I believe that these issues can affect the subtask and the subtask articulation and therefore also affect the vulnerabilities of the system. The usability attribute 'well articulated' will also further be presented.

4.1. Increase the number of subtasks performed by machines - reduce the number of subtasks performed by humans

Reijnders-Thijssen[15] commented on, as mentioned in chapter three, what she called a technology push in radiotherapy. According to her, radiotherapy was one of the fastest developing technologies in health care. She argued that this was both due to the integration of information technology, but also to the whole process around radio technology getting more and more computerised. Many of the subtasks that earlier were done by humans, had now been changed to technical subtasks. The increasing use of the computer had changed the way they worked. She stated that "...before our employees were more concentrated on treating patients as individuals, but now they are more concerned on pushing buttons and trying to keep the technique running"[16].

Most of the software systems used at the MAASTRO clinic communicated with each other. The key software working together was the XIO (the planning system) and COHERENCE (an assembly of different software the operators use during the treatment of a patient). One of the software integrated in COHERENCE was LANTIS (the patient information database). The images from the CT were used in XIO to plan a patient's treatment. The treatment plan was then transferred to and stored in LANTIS. When a patient was scheduled for a treatment, the operators fetched the treatment plan from LANTIS, and the plan fed the accelerator with the parameters needed for the treatment. Through LANTIS, the operators had access to all the information the clinic had stored about the patients. Some of the software installed at the MAASTRO clinic was developed by Siemens, but not all. XIO was not developed by Siemens, and it was not compatible with LANTIS, or the other software

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15 Interview with Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

16 Ibid.

Siemens had developed. To bridge this gap, the MAASTRO clinic had developed DigiTrans. DigiTrans was a software program that made it possible for all the different software to communicate. For XIO to be able to communicate with the software systems, DigiTrans had to convert the data stored in XIO to fit with the way data were stored in LANTIS. LANTIS did not perform any safety checks on the date stored in its database, so they had also included safety checks in DigiTrans. DigiTrans checked the data going from one system to another. Creating DigiTrans so that the software systems were able communicate, and implementing safety checks into it, were done, among others, to increase the safety and the control in the clinic. I believe that the subtasks performed by DigiTrans, the converting and the checking, are subtasks that need special attention because the subtasks' reliability is very crucial for overall system reliability.

The increased use of computer based equipment in radiotherapy has implications for many different areas. As mentioned above, the MAASTRO clinic experienced that the machines gradually took over tasks they used to do manually. The operators at the MAASTRO clinic could now fetch data from LANTIS over and over again. The data only needed to be entered once. The operators performed the subtask of fetching data instead of repeatedly performing the subtask of entering data into the system. The implementation of DigiTrans also reduced the need for humans to perform some of the subtasks that used to be manual. DigiTrans removed, among others, some of manual checks the operators used to do on the linear accelerators used prior to their move to Maastricht. One of the interviewees reported a slight feel of uncertainty with this new procedure. The interviewee did not like the idea that the treatment variables went strait to the machine without being manually checked first. The interviewee admitted that this new way of working was more effective, and that the uncertainty probably would fade away quite quickly[17]. One issue the interviewees reported to be a problem with this automation, was connected to the possibility of incorrect data in the LANTIS database. If a variable was incorrect, and no part of the system managed to detect the mistake, the patient could be treated with wrong variables an unknown number of times[18]. This is a clear example of a situation where the subtasks in the 'articulation zone' between the subtask of planning and the subtask of treatment are not well articulated. Mistakes like these are closely related to bad subtask articulation. As the interviewees said, these kinds of misses were only detected by chance. They described it as a feeling. Sometimes an operator felt something was wrong, performed some additional subtask checks to see whether or not they could detect some sort of deviation. Improving the articulation between these subtasks might reduce the chances of mistakes like these to happen. I am in no position to make suggestions to how the clinic can improve their subtask articulation, but I will in the next chapter comment on the visibility of subtask articulation which I believe is closely connected to the ability of detecting subtasks that are not well articulated.

4.2. Vulnerability and uncoupling

Uncoupling is a term used by different scholars to describe something that should be closely connected, have integrated functionality, but for different reasons is not as integrated anymore (Snook, 2000; Rosness, forthcoming). Looking at the term from a subtask level, uncoupling can refer to the opposite of subtask articulation. Many of the different subtasks performed at the MAASTRO clinic had to be very well articulated for the system to perform reliably. The clinic's focus on detecting process deviation showed their awareness of the effect uncoupling could have on their system. As Reijnders-Thijssen said, because the work done at the clinic

17 Interview with Claudia Offerman, Radiation Technologist, MAASTRO clinic, June 20, 2006

18 Interview with Jeroen Baltussen, Radiation Technologist, MAASTRO clinic, June 2, 2006

was so process centred, they had to look for process deviation to improve patient safety. In the following, I will look at how different types of uncoupling can affect the vulnerability of the MAASTRO clinic, I will also present the way the MAASTRO clinic tries to hinder this from happening, and look at the effects of their efforts.

4.2.1. Protocols, rules and control; How does it affect safe and reliable performance?

Rules and regulations are often viewed as a two edged knife. Rules and regulations are often used to control the subtasks and way people are work in order to limit the number and seriousness of accidents. On the other side, accident analysis shows that rules and regulations can also be part of the cause of an accident (Reason, 1997; Coeckelbergh & Wackers, forthcoming). “In crisis situations there can be a tension between regulation and responsibility: sometimes acting responsible may require people to override rules” (Coeckelbergh & Wackers, forthcoming). The idea is that complying with rules and regulations is not always the best thing to do, and that non-compliance can be appropriate in some situations. Non-compliance should not be equated with guilt, because “…any pre-programmed procedure can be inappropriate in certain circumstances” (Reason, *et. al*, p. ii23).

As mentioned in chapter three, the radiotherapy technologists were also the ones who made the treatment plan. The radiation technologists at the MAASTRO clinic rotate on these different tasks. They spend some days on the CT, some days planning treatments, and some days treating patients. This way of working was not unique to the MAASTRO clinic, and, as one of the interviewees informed me, there were also clinics that did not practice rotation. These clinics had more specialised operators at each step[19].

The interviewees reported that they enjoyed this way of working. They said that it both made their work more varied, and made them able to evaluate and control the work done by the other radiation technologists. This way of working can be connected to the operator's ability to detect that something is wrong, for example to detect that a subtask has not been done. Rotating on the different subtasks performed creates a control element without implementing tools or strict rules and regulations. The control is connected to the knowledge of the workers. I will not go into whether or not making the operators versatile in as opposed to specialists will benefit system reliability, but only comment on the effect this way of working can have on the overall work being done. In connection to the issue of non-compliance mentioned earlier, the way they worked at the MAASTRO clinic might have a positive affect when something out of the ordinary happened. Since the operators were not guided by strict rules, their ability to react responsible might be better that if they had been controlled more strictly. In addition of being a positive asset, one of the interviewees also reported that this internal control might make the operators work more carelessly because they trusted that their co-workers would detect any mistakes made. This effect might affect the articulation between subtasks in the clinic, and therefore also affect the reliability of the system.

As mentioned earlier, Snook's theory on practical drift discusses the effects rules and protocols can have on organisations (Snook, 2000). In his thorough analysis of the accidental shootdown of two American helicopters over Northern Iraq, he shows how the organisation drifted away from the developed and implemented rules and protocols. The main reason was attributed to the fact that the organisational subunits developed a more practical

19 Interview with Jeroen Baltussen, radiation technologist, MAASTRO clinic, June 2, 2006

way of working. The protocols were designed to fit an organisation that was highly integrated, but after a while in operation, the system characteristics changed, and the integration between the different organisational subunits were not as integrated anymore. Snook looks at how the organisation was designed to work, and compares it to the state it was in when the accident happened. The different subunits developed more practical ways of working. The reason why the implemented protocols and rules failed at identifying the helicopters as friendly was that the subunits had not worked according to these protocols prior to the accident; hence the integration between them was reduced. Due to the reduced integration of the organisational subunits, the system wrongly identified the helicopters as enemies, and shot them down.

Moving the focus to the MAASTRO clinic, the work done at there was guided by two different kinds of protocols: Medical and technical protocols[20]. The medical protocols were developed to guide medical doctors to the correct standardised treatment corresponding to the type and the position of tumour the patient in question had. The technical protocols, on the other hand, informed the operators on how to use the different machinery. In addition to these more standardised protocols, the ways the operators worked were also guided by rules and agreements. Some of the subtasks performed by humans were strictly governed by rules. Other subtasks were only guided by what the interviewees described as agreements. The agreements described what needed to be done, but they did not specify who should do it, or when it should be done. It was the group’s task to divide the work between them, and as long as all the subtasks connected to the process were performed, the system performed reliable. One example of an implemented agreement was the agreement connected to the subtask of treating patients. The team of three was, as mentioned above, divided in two. One operator worked inside the control room, and two other operators worked inside the treatment room.

20 Interview with Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

The different subtasks that needed to be done, was not strictly divided between the three operators, but it was the operators' jointly responsibility to perform all the subtasks. Some of the interviewees reported concerns connected to the lack of strict rules guiding the process of treating patients with radiotherapy, and said that they were looking into the possibility of implementing these kinds of rules in the clinic. Comparing this situation to the discussion on compliance and non-compliance in the beginning of this chapter, the lack of strict rules might make the operators better equipped act responsible instead of complying with governing rules and agreements. As mentioned above, this non-compliance can in some situation be the safest way to react.

In addition to these protocols, the MAASTRO clinic also used the PRISMA tool to evaluate near miss and miss incidents to continuously improve they way they work. The MAASTRO clinic had regular meetings where they, among others, discussed the results of these analyses. The MAASTRO clinic used the result from the PRISMA and the HFEMA analyses to improve the way they worked. During these meetings, the operators or the managers presented more efficient or safer ways of working, and the group discussed and analysed whether or not the suggestions would benefit the work at the clinic. Because these decisions were taken jointly, the clinic believed that they were more reliable. Since they also did it on a regular basis, they managed to alter the way they worked, if needed, quite frequently. This way of working can be viewed from two different points of view. On one hand this removed unsafe ways of working quite quickly. On the other hand, this made the correct way of working change quite often, and the operators needed to keep track of which way was the latest and correct way of working. One of the interviewees mentioned that this was sometimes a problem. "Some things change quite often, and I think that is a problem for patient safety"[21]. The clinic's ability communicate the correct way of working, the subtask of informing the operators, were closely connected to the operators ability to work according to this agreements. The articulation between the subtasks affected the correctness of the work done in the clinic.

Applying Snook's theory of practical drift directly to the MAASTRO clinic is not strait forward. The work done at the clinic was not as guided by protocols and rules as the military operation in Snook's theory. Also, the work done at the clinic was located in the same building, so it was easier for the operators to communicate. Compared to the military organisation in Snook's theory, where the work was done on different locations and by different units, the work at the MAASTRO clinic was more localised. Since the radiation technologists rotated on the different roles, they all knew how to perform the different subtasks of the system. Due to the continuous focus on, and analyses of the way they worked, they were also able to evaluate the present way of working. This made the situation very different from the state in Snook's analysis. But, there are scholars who have shown how to apply Snook's theory of practical drift to organisations like the MAASTRO clinic. Wackers and Kørte (2002, p. 13) state that "all organisations are subjected to drift". As opposed to mechanical production systems that have tools to monitor drift, organisations working with design, maintenance or operation do not really have a sophisticated tool to monitor the potential drift (Ibid.). Based on Snook's theory of practical drift, they state that organisations vulnerable to drift ought to develop a culture and a routine within the organisation that helps them evaluate and collectively focus on the way they work, their protocols and routines, and the way it develops to carefully look for drift. The MAASTRO clinic continuously focused on the way they worked. They worked hard to develop an organisational culture of reporting

21 Interview with Pascale Simons, Radiation technologist, MAASTRO clinic, June 20, 2006

failures and near miss incidents. Because radiotherapy is very process centred and standardised work, they focused on detecting process deviation[22]. Through analysis and discussions, they tried to make the way they work safer. As one of the interviewee's stated: "We have a problem with the visibility of failures in radiotherapy. That is one of the reasons why we look for deviations in our processes"[23]. I believe lines can be drawn between the suggestions made by Wackers and Kørte and the way they work at the clinic. They tried to keep a close look at the way they worked, and at the way it developed. But, as Wackers and Kørte (Ibid., p. 13) also state: "A focus on vulnerability is very different from an outcome and event-based management strategy". The evaluation process at the MAASTRO clinic does carry with it some of these management strategy characteristics, but since they do not only base their evaluations on statistical data, they have increased their probability to detect drift, or process deviation, through their evaluation methods. The fact that they also continuously evaluate each other through rotation, can also affect their ability to detect and avoid mistakes. But, their ability to detect process deviation is connected to the subtasks that are visible. They are not able to detect process deviation, or any other kinds of drift, if the subtasks are not visible. I will return to the usability attribute of visibility in the next chapter.

4.2.2. Uncoupling of development

The software systems implemented at the MAASTRO clinic was not all developed by the same company[24]. The software systems perform many of the system's subtasks, and contributed to the clinic's ability to perform their main task, treating patients. The integration of the different subtasks, being done by humans or machines, was crucial for the clinic's

22 Interview with Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

23 Ibid.

24 Information retrieved during interviews at the MAASTRO clinic

ability to perform safe and reliable. LANTIS, COHESION, and the software controlling the accelerator were all developed by Siemens. The integration between these software systems, and the subtasks they perform, are much tighter than the integration between software systems developed by other companies, if the systems are able to communicate at all. One example is the planning system XIO. As mentioned earlier, the planning system had to be implemented on separate and stronger computers than the other software programs used in the clinic. Without making the proper adjustments to make these all the software systems able to interact with each other, the work done at the MAASTRO clinic would have been quite different. To reduce human handling, and to enable the different software systems to communicate, the MAASTRO clinic had developed DigiTrans. If the clinic had not made this patch to make the different software systems communicate, entering the same data more than once could have been one of the consequences. This would have both been a time consuming process, and it could also have resulted in mismatches between the data entered into the different systems. I have earlier commented on the negative effect this automation can have on patient safety. My point here is that automating subtasks like this can both have a positive and a negative effect. This is one of my arguments for why I believe the ‘subtask perspective’ can contribute to the reliability of system performance. Choosing one solution over the other does not mean that the system will perform reliable forever. The fact that systems and subtasks develop and change makes it necessary to continually monitor the state of the system.

DigiTrans made data from one software system available to another. It also checked the validity of the data before it transferred it to the desired destination. To be able to use the plans from XIO in patient treatment, DigiTrans transfers the data to the LANTIS. The interviewees reported that since there were no quality checks implemented in LANTIS, DigiTrans had to be developed to check the data before it was stored in LANTIS. The development and implementation of DigiTrans is one clear example of the uncoupling of development (Wackers & Kørte, 2002).

> "The rapid development of transport systems, information technology, and just-in-time schemes leads to a high degree of integration and coupling of systems and the effects of a single decision can have dramatic effects that propagate rapidly and widely through the global society" (Rasmussen & Svedung, 2000, p. 10).

As further discussed below, developing a patch, like DigiTrans, between two different software programs might increase the vulnerability of the system. Without going further into the way DigiTrans worked, and the way it was developed, I would like to draw lines from the development and implementation of DigiTrans at the MAASTRO clinic to literature covering similar solutions. I am in no position to claim that the MAASTRO clinic has experienced any increased vulnerability due to DigiTrans, but I want to point out possible effects such patches can have. The topics presented in the following are meant to be examples of the potential effects these kinds of modifications can have on subtask articulation and system vulnerability. The reason is that systems not developed together, or systems modified or extended without having the development closely connected to the already implemented parts of the system, can end up as uncoupled. Uncoupling of development occurs when systems developed separately are set to cooperate and work together with already implemented ones. One example is when a software system is implemented to handle the safety checks of the system. The whole system is then as safe as the safety system is able to keep it. Even though the performance of the safety system is reliable on its own, it does not automatically mean that it is able to handle all the situations that might arise in the system it is protecting.

Another situation of uncoupling of development can be described when the safety system is not reliable on its own. This is the case in Wackers & Kørte's (2002) article analysing the helicopter accident in the North Sea mentioned earlier. The helicopter manufacturer was not involved in the development of the monitoring system HUMS. (Wackers & Kørte, 2002). The monitoring system implemented to increase the safety of the organisation did not fulfil its intended task. Even though this was a large problem, Wackers and Kørte (ibid.) did not attribute the cause of the accident to the monitoring system alone. They stated that the reason why the accident happened was more complex. One of their main points in their article was that when designing and implementing modifications to systems, you need to also consider the redesign of the organisation. The organisation had to evaluate how the organisation should handle potential drift in the system. I want to use this conclusion to underline my argument for why I believe that analysing subtasks can have a positive effect on detecting and handling system vulnerability. As Wackers & Kørte states, when doing modifications, the whole system needs to be evaluated. I believe that one way of doing this evaluation is through this subtask perspective. One needs to look into all the subtasks the modification will affect, and also to evaluate how this can affect the overall system and the system vulnerability.

4.2.3. Subtask articulation, reliable performance

One problem that affected the working conditions for the radiation technologists at the clinic was the downtime of the machines. The accelerators often broke down for different reasons, both connected to the linear accelerator and to DigiTrans. When I arrived for my interview on June 2, 2006, only two of five accelerators in the clinic were working. Even though the technicians managed to fix one of the broken ones during my stay, problems like this had a huge effect on the work done at the clinic. One of the reasons for why the linear accelerators did not work was, among others, connected to DigiTrans. It performed, as mentioned earlier, different subtasks in the system. Sometimes, as the interviewees reported, DigiTrans was unable to fulfil its task of connecting the different software systems together. In these situations, the whole process of treating patients on the linear accelerator came to a complete stop. In these situations, the subtasks performed by DigiTrans, and the subtasks that connected DigiTrans to the rest of the system were not well articulated. To be able to perform according to plan and to achieve performative closure, the performance criteria for the system as a whole was, on an 'individual' level, to treat patients as planned, and on a 'global' level, to treat all the patients scheduled for the day. I am in no condition to evaluate whether or not these problems connected to DigiTrans had something to do with uncoupling of development, but I only want to point out that lack of reliable performance is also a problem that can be connected to the uncoupling of development. What I will do, is to comment on some of the vulnerabilities that entered the clinic as a consequence of DigiTrans and the accelerators not working properly.

These events affected the vulnerability of the clinic through the stressful situations they created. For the operators to be able to treat patients, DigiTrans had to run properly. One way of solving this problem was to move the patients to a different accelerator. This could only be done if there were other working accelerators available. The reduced number of working accelerators often caused the number of patients scheduled for a treatment to exceed the capacity of the system. The radiation technologists reported that it was very important to treat the patient according to the scheduled number of treatments each week. They really did not want to send anyone home due to a technical problem, and did everything possible to treat all the patients scheduled each day. This often resulted in operators working faster. The interviewees admitted that these situations caused a lot of stress, and that the amount of near miss incidents and miss incidents most likely increased. These situations, as the interviewees reported, affect the accomplishment of some of the subtasks in the system. One of the subtasks mentioned was reporting near miss and miss incidents in PRISMA. The operators found a more practical way of working, which, according to Snook, could result in practical drift (Snook, 2000).

The interviewees also reported that they sometimes had to leave out some of the subtasks or procedures scheduled, due to machine trouble. One example was controlling the placing of the patient. As mentioned, the operators placed the patient according to marks on the patient's body[25]. During a patient's treatment, the patient's position was checked regularly. These kinds of checks could also be performed when an operator was uncertain about the correctness of the placement of the patient. These checks had to be done on the linear accelerator, and were performed by comparing an x-ray of the tumour and the area around the tumour to a picture taken at the linear accelerator. The operators checked whether the patient's position was corresponding with the location of the tumour. According to the interviewees, the linear accelerator was not always able to perform this subtask, it did not always work the way it was intended to. Because this subtask was not regarded as very crucial for patient safety, they continued with the treatment even though they were unable to perform the subtask check. I believe that lines also can be drawn between these examples and Snook's (2000) theory of practical drift. Due to the stress experienced in the clinic, the operators moved away from written procedure to a more practical way of operating. In their stressful work environment, they prioritise the tasks they found most important, and that was to treat the patients scheduled for that day. As reported by the interviewees, cancer patients treated with radiotherapy should be treated as scheduled for the treatments to be as effective as possible. The stressful situation experienced by the operators at the MAASTRO clinic happened as a result of subtasks not performing the way they should. There was a lack of subtask articulation, and the operators had to find other ways of working. They had to work

25 Interview with Jeroen Baltussen, radiation technologist, MAASTRO clinic, June 2, 2006

around the subtask in question.

Before Siemens and the MAASTRO clinic had managed to make the linear accelerators and DigiTrans perform more reliable, this would be a source of increased vulnerability in the clinic. Because the problem with these subtasks was so visible to the operators, the clinic was well aware of its existence, and the effect it had on the clinic. Even though they were aware of the problem, the lack of subtask articulation increased the vulnerability in the clinic.

4.3. Summary

In this chapter, I have looked at how different elements can affect subtask articulation, and therefore also, according to my 'subtask perspective', the vulnerability of the system. I started off presenting how subtasks earlier performed by humans have been changed to subtasks performed by machines. This made the work done at the MAASTRO clinic both safer, and more effective, but is also increased the possibility of mistakes, slipping through the safety checks, affecting the treatment of a patient more than once. I continued by discussing the role of rules and regulations. Due to the stressful situations the downtime of DigiTrans and the linear accelerators created, the clinic experienced drift from the written procedures in the clinic. In stressful situations the operators failed to report all the near miss and miss incidents happening in the system, and they also left out subtasks that were defined as non critical for patient safety. The MAASTRO clinic worked hard to avoid process deviation, an as I commented above, this might positively affect the potential drift the clinic could experience. The examples above show how important it is for subtasks to articulate with each other, and to perform reliably. The issue of uncoupling of development was also discussed in this chapter. Since the MAASTRO clinic had to modify their system to make the different software systems communicate, they might have increased the vulnerability of the clinic.

Because DigiTrans performed safety checks of the data, the systems ability to perform became very dependent on this software. Both to be able to perform their main task of treating patients, and the level of safety the data used for treatment had. These topics show both how complex subtask articulation can be, and why it is important to be aware of these situations. I also believe that they work as good arguments for why the ‘subtask perspective’ can help a system like the MAASTRO clinic to monitor their system to avoid vulnerable situations to arise.

I am in no position to imply that the MAASTRO clinic does experience increased vulnerability due to the implementation of DigiTrans. But, I believe that they should keep a close look at the subtasks performed by DigiTrans to reduce the possibilities for DigiTrans to affect the system vulnerability. As mentioned earlier, for the whole system to perform reliably, the different subtasks need to be well articulated. The MAASTRO clinic is very dependent on their subtasks. And, as presented in chapter three and chapter four, different things can affect the subtasks and the subtask articulation, and therefore the systems ability to perform reliably. In the next chapter, I will increase the focus on the usability and especially on the attribute of visibility of subtask articulation and 'articulation zones' in the system. I will continue to argue why I believe the concept of usability can fruitfully be transferred to the ‘subtask perspective’ sketched out here, to increase a system’s ability to detect and reduce system vulnerability.

5. Transferring the concept of usability to subtask articulation and 'articulation zones'

In chapter four, I used my findings from the MAASTRO clinic to exemplify why I believe that system's can positively affect their vulnerable state through a 'subtask perspective'. Being aware of the different subtasks of a system, the role they fulfil, the instabilities or imperfections they might have, and also how modifications and change might affect the system, can make systems more robust. In this chapter, I will continue my argument for the need for this 'subtask perspective', and also continue the transfer of the concept of usability to it. The main topic of this chapter is the usability attribute of visibility and its relation to vulnerability. I will argue that increased visibility of subtask articulation can increase the system's ability to recognise vulnerability.

5.1. Applying usability to the subtask perspective

As mentioned in chapter two, my definition of usability is much closer to safety and reliability than the traditional way of defining it. My definition of usability is also, as within the traditional way of defining usability, a quality attribute. The main difference is that my definition is closely connected to the terms resilience, robustness and reliability. Usability, in my perspective, is a dynamic value. The subtasks of a system, how they are articulated, and the usability of the 'articulation zones', develops and evolves. The same counts for the vulnerability of a system. It is dynamic (Bijker, 2006). In my subtask perspective, the usability of a system's subtasks can be very closely linked to the system's ability to handle vulnerability. A robust system is better equipped to handle an unforeseen event, than a system without this quality.

At the MAASTRO clinic, the number of subtasks that had to be done manually had gradually been reduced. The result of changes like this increased the complexity of the system. This is where the concept of visibility enters my argument. In the process of making a system safer, the overall complexity of the system might increase through the implementation of technical systems that take over subtasks earlier performed by humans. Since the main part of this increased complexity is connected to technologically handled subtasks, they are often hidden inside the technological part of the system. A system's visibility is closely connected to its vulnerability, because it, among others compromises the system's ability to anticipate an unforeseen event (Wackers, 2006).

As illustrated in chapter two, the MAASTRO clinic had different ‘articulation zones’ on the different levels of aggregation. During my interviews at the MAASTRO clinic, the information I gathered was mostly connected to the 'articulation zones' between humans and machines, and between humans, because this is what the operators at the clinic had experience with. The 'articulation zones' between technological subtasks are not as visible to the operators. This is one of the reasons why I believe it is important to focus on the visibility of some of the more hidden subtasks. I will base the following on the information gathered during my interviews at the MAASTRO clinic, and since a lot of the subtasks studied were subtasks performed between humans and computers, some of the arguments in the following do have close resemblance to traditional human-computer interaction. I still believe that my analysis differs a lot, because it deals with the 'articulation zones' and not only connected to the user interface.

5.2. The visibility of radiotherapy

One problem with radiotherapy is that the results of a treatment are not really visible. By invisible results of a treatment, I am referring to the fact that the treatment does not leave any marks on the patient. As one of the interviewees exemplified, compared to a person who has been through an operation, there are no visible cut or marks after radiotherapy. This makes detecting failures difficult. If a patient is given an overdose, the results might not show for a long time. Exactly this was one of the problems in the Therac-25 accidents mentioned in text box 1. The operators had been told that the Therac-25 could not give overdoses, and due to the fact that they were unable to detect that the patient had received an overdose, they continued to treat patients who had already been given a deadly dose. Compared to the Therac-25 accidents, a lot has changed regarding the linear accelerators, and the safety connected to the process of giving radiotherapy. One obvious difference between the MAASTRO clinic and the Therac-25 cases is that all the treatments done at the clinic are stored in LANTIS, so the operators are able to go back to a treatment and check whether or not it was correct. The results of the treatments have been made more visible.

One way of increasing the visibility of radiotherapy, could be to copy the way visibility has been dealt with using gas for cooking in kitchens. The gas was originally odourless, but due to the dangers connected to gas leakage, they have added smell to the gas. This idea could also be applied to radiotherapy. To make radiotherapy more visible, one could add colours to the beam sent from the linear accelerator. Different colours could represent the different levels of radiation. If the operators knew what kind of colour to expect, they might be better equipped to detect when something went wrong.

The interviewees mentioned that patients treated at the MAASTRO clinic sometimes were treated with the wrong dose, or wrong treatment field, but they had not experienced anything really serious during the last twenty years. There are some ways to correct treatments that have either been too small, too large or been a bit misplaced. To be able to do so, the mistake must be detected. To correct failures like this, they could alter the rest of the treatments, so that the patient in the end received the same amount of treatment as planned from the beginning. But, as mentioned above, the mistake had to be detected, and the interviewees reported that they did believe that mistakes like this managed to slip through the safety checks of the system.

5.3. Why visibility matters

My main argument in this section is based on my assumption that visibility is closely related to both the system's ability to hinder the creation of undesired vulnerability, and to the system's ability to detect them. The visibility of subtask articulation and 'articulation zones' can therefore positively affect the system’s 'reduced ability' to handle unforeseen events. The visibility of subtask articulation can increase the system’s ability to monitor the different subtasks, and therefore also keep track of the state of the system. Subtasks articulation can be both visible and invisible. I do not define the terms as absolute, but the quality is a continuum ranging from very visible to not visible at all. Some of the subtasks are naturally visible to the operators, others are more hidden inside the technical part of the system. Examples of visible subtask articulation can be subtask resulting in messages on the user interface of a machine in use, or one operator watching another perform a subtask. Less visible subtasks are the subtasks done inside the technological part of the system. These subtasks can also be visible, but that is more connected to whether or not checks and controls make them visible in one way or another. One example is the error messages given to operators. This kind of error messages, or their subtask articulation, often refer to subtasks the technological part of the system is unable to perform. Whether or not the users find the message informative has to do with the visibility of the message. Does the user understand the message? Does the user have to look up the message in a manual to understand it? Are the operators able to solve the problem? In the situations where the user has to look it up in a manual, the subtasks articulation is not good, and an additional subtask is needed for the subtask to be understood. This was one of the problems the operators from the Therac-25 accident referred to when asked about whether or not they understood the state the system was in.

The information given to the operators, from colleagues, user interfaces, or analysis reports, is crucial for their understanding of the state the system is in. The communication between the subtasks in the 'articulation zones', is important for the ability of the system to detect vulnerability and to react to undesired events.

Moving to the visibility of the subtasks and subtask articulation in the MAASTRO clinic, the interviewees reported that they were very pleased with the user interfaces of the new linear accelerator installed. Referring to the traditional way of defining usability, they reported that it was easy to learn, easy to understand, and easy to remember how to operate it. "The screens are more visual. You can see better what you are doing. They are more complex, but easier to use. They are more visualised"[26]. They also positively commented on the change from the more numeric interface they used in Heerlen to the more visualised interface the new system had:

> A lot has changed. The machines we used in Heerlen only showed information through numbers on the screen. When there was a deviation between planned parameters and entered parameters, the screen showed a "*" before the corresponding number. Now this has changed, the machines we use here in Maastricht are more visual. They work with colours. [27]

There is a clear difference between the visualisation of a user interface, and the visibility of subtasks. As mentioned earlier, despite all the safety checks implemented to increase patient safety, failures manage to slip through.

The interviewees reported a visibility problem connected to some of the subtasks performed by COHESION. The problem was connected to COHESION's inability to visualise

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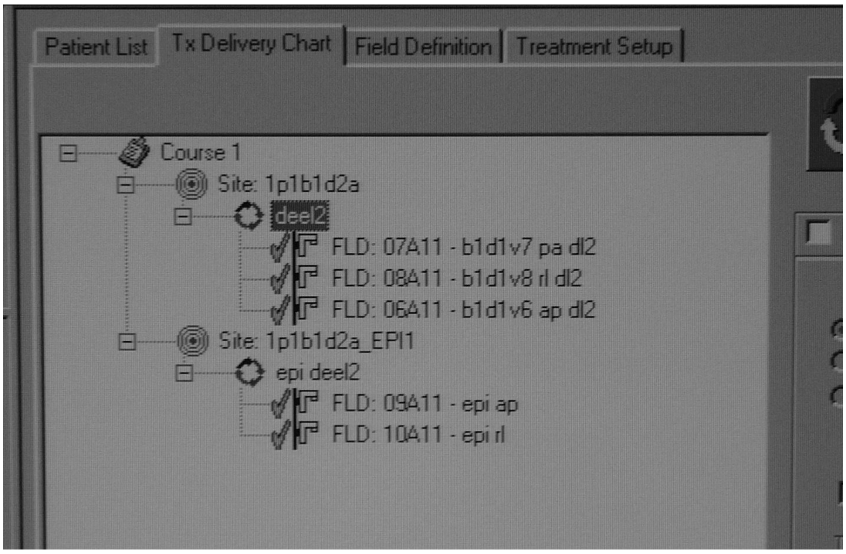
26 Interview with Anike Lumens, Radiation Technologist, MAASTRO clinic, June 20, 2006

27 Interview with Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

that a patient had been treated two times per day. The first time a patient came in for a treatment, the user interface of COHESION showed all the treatment fields. After a field was treated a green tick appeared before the field (see picture 4).



Picture 4: Making the completion of a subtask, the subtask articulation, more visible to the operators

This tick informed the operator that the field had been treated, and made the subtasks performed by the linear accelerator more visual to the operators. When the patient had been treated from all the angles scheduled, the number of green ticks corresponded with the number of angles. When patients scheduled for two treatments per day arrived for their second treatment, the ticks from the first treatments were still visible. The operators were able to treat the patient for a second time, but since the system did not handle these situations, the subtasks performed by the linear accelerator became less visible. This situation caused two distinct problems. The first was connected to the fact that the operators could not distinguish between the fields they had radiated and the fields that were left, the second problem was that when they tried to radiate the second time, a warning message popped up asking whether the operator wanted to radiate for the x time. The first problem could result in operators leaving out fields from the treatment. The second problem could result in the operators radiating the same angle more than the number of times scheduled. The interviewees admitted that it was easy to become immune to those kinds of messages from the linear accelerator, and that they pressed OK without even reading them. The combined result of these two problems was that they could radiate one field more than twice and others not at all[28]. Wackers & Kørte (2002) describe a similar episode in their article on the helicopter accident in the North Sea. Because the operators were used to the monitoring system giving to many false positive alarms, they had become immune to the messages. Nielsen (1993) has also described situations like these. He said that designers often try informing users through messages on the user interface. In some situations messages like this can be helpful, but if users experience them too often, they might ignore them. Then the user end up, like in the situation at the MAASTRO clinic, by ignoring the message. Due to the fact that the operators became immune to the messages, the messages became invisible.

The interviewees also reported another problem that had to do with the visibility of information. This problem was connected to the subtask that had to be performed on patient's who had a treatment plan that included non standardised procedures. Information about these situations was given to the operators through COHESION. The operators had to pay close attention too this information because there were no safety systems implemented to check that these tasks had been done. One example was when the tumour was located close to the surface of the skin. To increase the dose at the location of the tumour, the screen informed the operators that they had to put a piece of material, a bolus, on the patient. If the operators forgot to perform this subtask, the patient was not treated according to the treatment plan. The articulation between the subtasks performed by the machine, informing the operator, and the operator receiving and performing the subtask in question, was not well articulated, and could

28 Ibid.

therefore contributed to the system's vulnerability.

Inside the treatment room there were two monitors on each side of the linear accelerator. The screens showed exactly the same information as the two screens in the control room, the interface of the accelerator and COHESION (see picture 2 and 3). Among others, these screens informed the operators about how to place the patient, the placement of the treatment table, patient specific information, and whether or not the machine was ready to radiate. One problem reported by the interviewees regarding these screens, was that they were too small. The operators were not able to read the information on the screens while they positioned the patient. They had to move towards the screens to be able to read the information on them. The clinic had tried to solve this problem by implementing the largest screens Siemens had, but they were not large enough. Due to the space needed by the linear accelerator (see picture 1), the screens had to be placed quite far away from the treatments table. The subtask of providing the correct information to the operator, so the operators could perform their subtask, was not well articulated. The information on the screens was not visible for the operator when the operator needed it. This is a clear example of two subtasks that are not well articulated. In this example there was nothing wrong with the visibility of the subtask per se, but they were not visible to the operators when they where in their working positions. The information was on the screen, but the operators were not able to read it. The MAASTRO clinic had found a temporary solution to the problem with the screens, but the solution also increased the possibility of making a mistake. For every patient, the operators printed out the patient information given on the screens. This made them able to place the patient and the table without moving back and forth between the table and the screens, but the additional subtask increased the complexity of placing a patient.

5.4. The visibility and invisibility of subtasks - the systems ability to anticipate

In safety critical systems, organisations often implement different safety features to make the system safer. As mentioned in chapter three, according to Reason (1997), the ideal defence should be tight, intact, and not let any of the hazards lurking behind get through. But as he continues, the reality is not that perfect. Technology can run reliably for a very long time before something happens, and the defence layers, or as he calls it, defences-in-depth, looks more like a stable of slices of “Swiss cheese” than a solid wall. The “holes” in the layers of the cheese are often of both a static and a dynamic character, and there are different reasons for why they are present, and why they develop. If one defence layer does not detect and stop a failure, and the failure slips through the hole, there is a big chance that the next layer catches it. Relating this to the safety measurements I have mentioned in this thesis, a mistake will have to slip through the three manual checks, and the checks performed by DigiTrans. The problem arises if the incident or hazard, manages to pass all the defence layers without being detected and stopped. It is in these situations failures or accidents happen. In addition to try to keep the system safe, these different kinds of safety features also hide the failures and mistakes that exist in the system from the people working in the system. The dangers are invisible for the rest of the system. When the safety systems hide the failures inside the technical part of the system, the people that are interacting with the system are unaware of them, and are therefore not prepared for, or used to, these failures and mistakes happening. The people working in systems like this are not really prepared to handle mistakes or possible failures. The result of these kinds of situations can be linked to situations where the vulnerabilities of the system has been hidden, or invisible for the operators, so the operators are unaware of the state of the system. The result can be a reduced ability to reduce or recover from the accident (Wackers, 2006).

The MAASTRO clinic continually tried to reduce, and to do something about the failures and process deviations detected in the clinic. They reported that they focused mostly on the organisational and the technical failures, because it was very difficult to do anything about human failures. As one of the interviewees stated, making errors is a part of being humans. Humans are not error free[29]. I believe that the clinic's strong focus on errors, and their perception of human failures, are to narrow. As a solution to humans making errors, one of the interviewees said: "We would like to have a kind of black box. If you look at the screen of the accelerator, you see all the parameters we have to check. I believe that you should not be able to see all the parameters that are correct. You should only see the parameters that really have to change"[30]. This is also an example of how the state of the system can get more and more hidden from the operators. If all the checks and controls are done by the system, the operators would not be well suited to handle and recognise a vulnerable situation or the emergence of an undesired event. 'Black boxing' the interface show how much people trust technology, and the reliability of technology. Complex systems are not basically safe, and to improve the safety of a system, one has to practice it on all levels of the system (Dekker, 2006). 'Black boxing' the user interfaces of the computer based systems might seem like an idea that would help the operators performing their subtasks reliable, but it would at the same time make a lot of the subtasks of the system invisible. An interface like this leaves all control to the technological system, and the result is that only the system is able to control whether or not the situation or the system is safe.

I am not saying that the only way to make a safe system is to make all the subtasks visible. Topics like these have their own field of research, where the field of human-computer

29 Interview with Petra Reijnders-Thijssen, Manager of patient safety, MAASTRO clinic, May 26, 2006

30 Interview with Pascale Simons, Radiation technologist, MAASTRO clinic, June 20, 2006

interaction is one of them. My main argument here is that I believe it is important for a system's ability to handle vulnerability to be able to take this 'subtask perspective' and look at how it is all connected, how it is articulated. Vulnerability does not necessary arise as an immediate response to some change in the system, vulnerability might arise very slowly. Most complex systems perform with some level of vulnerability. The problems arise when the system is not able to handle the vulnerability any more, when an unforeseen event threatens the system's performance (Wackers, 2006). The enormous trust given to computers and their ability to perform reliably is a utopian trust. I believe that the 'subtask perspective' presented here is one way in the right direction towards a way to handle the vulnerability of complex systems. Transferring the concept of usability also show that the dynamics of the articulation between subtasks needs to be monitored because 'articulation zones' with good usability one day might have changed the next. As Thomas P. Hughes (1987, p. 51) states: "If a component is removed from a system or if its characteristics change, the other artefacts in the system will alter their characteristics accordingly".

5.5. Summary

I have in this chapter continued to transfer the concept of usability to my 'subtask perspective'. I have argued through examples for why I believe the concept of usability can fruitfully be used to focus more on safety and reliability. I have focused a lot on visibility because I believe the visibility of subtask articulation and 'articulation zone' is important for the system's ability to act in relation to a system's vulnerability. The way the concept of usability is applied here, has much more to do with safety and reliable performance than the traditional way of defining usability. I believe the ability to handle the vulnerability of a complex system is connected to the way a system monitors the state is in.

I have in this chapter tried to show why I believe that transferring the concept of usability to my subtask perspective might increase a systems ability to recognise vulnerability, and therefore also increasing the reliability and robustness of the system. My goal was to make the concept of usability more safety centred. As I have shown in this chapter, I believe that usability can be applied to different levels of a system. Through the different levels of aggregation, the concept of usability can be applied all the way down to the articulation of the smallest subtask. The different types of visibility presented here were connected to the hidden complexity of systems, invisible subtasks, the reduced visibility automated subtask, and the connection between visibility and the systems ability to anticipate that something is about to go wrong.

The next and last part of this thesis is the conclusion, where I will sum up the issues discussed in this thesis.

6. Conclusion

I have in this thesis transferred the concept of usability from the field of human-computer interaction to the 'subtask perspective' sketched out in this thesis. My goal was to include safety and reliability into the concept of usability, and I felt that the best way to do this was through the creation of a new perspective. My point of departure was the limitations connected to the traditional definition of usability as used in the field of human-computer interaction. Basing myself in the field of STS, and the research on vulnerability done from this field, lead me too the system perspective taken in this thesis. Since vulnerability is a concept that comprises a whole system, the unit of analysis had to be moved from the individual level taken in human-computer interaction to the system level taken here. The subtasks of a system and the articulation between them replaced the interaction between humans and computers in the field of human-computer interaction.

As stated in this thesis, vulnerability refers to the state of the system. Usability on the other hand refers to the quality of the articulation between subtasks performed within the system. Since I have argued for why I believe the quality of a system's subtasks affect the vulnerability of the system, usability is in a way the opposite of vulnerability. If the subtasks of a system are well articulated, the system performs reliable. When subtasks are hidden, not visible for the system, the system is unable to know what state it is in, or the quality of the subtasks performed. When subtask articulation and the 'articulation zones' have a high degree of usability, the system is more aware of the state it is in, and they are therefore better equipped to detect and handle system vulnerability and unforeseen events.

Through the analysis of the empirical data gathered at the MAASTRO clinic, my background from the field of human-computer interaction, and the field of STS, the outline of the perspective sketched out here emerged. My main goal in this thesis and for creating the 'subtask perspective' was to increase the awareness of the concept of vulnerability and to comment on the lack of focus on safety and reliability in the field of human-computer interaction. The clinic had such a considerable focus on patient safety, and how to make the operation of the clinic as safe as possible, so I wanted to closer at how their achievements affected the state of the system, both through its positive aspects and its limitations. I also wanted to create a perspective that could increase the awareness of what vulnerability is, and how it can arise in systems. Inspired by the field of human-computer interaction, I had to move quite far away from it, and only bring with me some of its core elements. Only the idea about interfaces, the 'articulation zones', and the altered concept of usability were included in my perspective.

The 'subtask perspective' sketched out in this thesis, can be summed up by three interrelated elements. First, through the perspective you can analyse a system's subtasks from different levels of aggregation. The level of aggregation chosen depends on what kind of system it is used on, and what kind of information is needed. In this thesis, I have mainly focused on the ‘general’ level of aggregation: the CT scanning, the treatment planning, and the actual treatment, and on the subtasks on the ‘individual’ level of aggregation: fetching patient information, checking patient information, placing the patient, and connecting the different software systems together. Most of these subtasks presented and discussed here are subtasks the operators, the radiation technicians knew existed. The reason for that is because they were my source of information. Given the ability to further develop this ‘subtask perspective’, I would also like to look closer at the subtasks performed by the technological part of the system.

The second element has to do with subtask articulation. For a system to be able to perform, the different subtasks of the system had to be articulated. Because the relation between subtasks rarely is on a one to one basic, I have included the term 'articulation zone' to imply an interface where different subtasks meets, articulates. The whole system depended on the quality, the usability of these 'articulation zones'.

The third and last element of the 'subtask perspective' is the transfer of the concept usability to the perspective. As within the field of human-computer interaction, I am using the concept of usability as a quality attribute, but in this perspective it has much more to do with safety and reliable performance. I have further divided the concept of usability into the two attributes ‘well articulated’ and ‘visible’. For the system to be able to perform reliable, subtasks had to be well articulated. By ‘well articulated’ I am referring to the importance of subtasks to be highly integrated with each other. A system is dependent on its subtasks and the articulation between the subtasks to be able to perform reliably. The visibility attribute has also to do with the subtasks and the articulation of subtasks, but it refers to whether or not the articulation is visible to humans or other safety mechanisms in the system. The result of the automation of subtasks in complex systems is that the subtasks get more invisible, and I believe that this invisibility can hide the vulnerability that can have arisen in the system. One of the main reasons why I believe that 'subtask perspective' can have a positive affect on a systems state, is closely connected to the definition of vulnerability used in this thesis. As I have argued in this thesis, the vulnerability of a system can arise when the usability of the system's subtasks is not good. For the system to be able to perform reliably, the systems subtasks need to be well articulated, and for the system to be able to recognise and act upon vulnerabilities that are about to, or have arisen in a system, they need to be visible.

Even though a system might perform reliably and safe for a while, it does not have to be like this for ever. Because the vulnerability of a system is dynamic, one has to continuously monitor it. Vulnerability can arise in all parts of a systems life cycle, from design and development to modifications and operational practice. Because vulnerability refers to a state, I believe there is a need to increase a systems ability to recognise and act upon that state. As the definition used in this thesis holds, a system's vulnerability has to do with their reduced ability to handle an undesired event. It is not the event in itself that causes an accident, but the accident happens because the system is not able to handle that event. This part of the definition also bear with it the arguments for why defining the cause of an accident as a human failure is to narrow. The undesired event, being caused by a human or other, is not the reason for the accident. This might even have happened before, but then the vulnerability of the system was different, and the system was able to achieve performative closure.

The perspective sketched out in this thesis is only in its initial phase. Given the opportunity to continue the development of this ‘subtask perspective’ might make it mature into a perspective one could apply to a complex system’s like the MAASTRO clinic to increase the clinic’s ability handle and detect vulnerability. As stated in chapter one, to study vulnerability through an STS perspective can be very fruitful. The vulnerability of our modern society is a consequence of the advanced technological development of our time. As mentioned earlier in this thesis, vulnerability is not only negative, and we will never be in the state of complete invulnerability. Due to this fact, we need to continue to research the concept of vulnerability, the causes and effects of it, to increase our understanding of it.

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Appendix

List of interviewees:

Petra Reijnders-Thijssen, Manager of Patient Safety, May 26, 2006

Jeroen Baltussen, Radiation Technologist, June 2, 2006

Aniek Luems, Radiation Technologist, June 20, 2006

Pascale Simons, Radiation Technologist, June 20, 2006

Bianca Hanbeukers, Radiation Technologist, June 20, 2006

Claudia Offerman, Radiation Technologist, June 20, 2006